

ACQUIRING TECHNOLOGICAL CAPABILITIES:
THE CNC MACHINE TOOL INDUSTRY IN
INDUSTRIALISING COUNTRIES, WITH
SPECIAL REFERENCE TO SOUTH KOREA

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ABSTRACT

This thesis studies the acquisition of technological capabilities in Newly Industrialising Countries (NICs). General problems concerning methods of learning and processes of economic and technological development are addressed by way of an extended case study of the development of the Computer Numerical Controlled (CNC) machine tool industry in South Korea from the mid-1970s to the mid-1980s. More briefly, material relating to the machine tool industries of Japan and Taiwan is mobilised for comparative purposes: the former illustrates the orientation and structural role of a recently matured East Asian industry which Korea seems in part to be following and the latter is an example of a successful NIC industry whose place in the manufacturing economy is markedly different from that of Korea.

The findings of the Korean study, and the Japanese and Taiwanese comparative materials, are brought to bear upon recognised questions concerning the contribution of a machine tool industry to an industrialising economy, the proper policies of NIC governments vis-à-vis that industry, and the methods of learning that have proved most effective in the acquisition of technological capabilities in developing economies. In broad agreement with the arguments of Nathan Rosenberg and many other analysts, it is argued that an indigenous machine tool industry may offer extensive and valuable support to the whole of the machine-using sector and that this can be a sufficient reason for government promotion.

A main aim of the study was to consider whether Korea, which had demonstrably acquired a range of capabilities in production, had started to acquire capabilities in the design and development of new products. The companies studied had relied to a great extent on foreign technology agreements as a mechanism for initially acquiring design and production technologies. However, these firms were not passive recipients in such agreements: several actively prepared themselves to learn by experimenting with the new product. A notable feature of the agreements was the transfer of skilled personnel, and the thesis argues that such direct interaction greatly facilitated the transfer of capabilities. The Korean machine tool industry is beginning to develop its own designs and to work with manufacturers in other sectors. Such inter-firm linkages were also found to be an important feature of the technological development of both machine tool producers and users.

The study points to a range of environmental factors that bear upon the acquisition of technological capabilities within the sample firms. These include the nature of the domestic market they supply (particularly requirements for specialised machinery for the emerging vehicle industry), their position within a business structure (especially the significance of conglomerate membership for technological interaction), and the nature of the technology itself. It is argued that an adequate understanding of the process of capability acquisition must consider the potential barriers constituted by different aspects of the product to be designed and manufactured.

I hereby declare that this thesis is based on my own research work and has been composed by myself.

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ABBREVIATIONS AND ACRONYMS

ATC	Automatic Tool Changer
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CIM	Computer Integrated Manufacturing
CKD	Completely Knocked Down
CNC	Computer Numerical Control
CPU	Central Processing Unit
DNC	Direct Numerical Control
EDM	Electro-Discharge Machine
EPB	Economic Planning Board (of Korea)
FA	Factory Automation
FMC	Flexible Manufacturing Cell
FMS	Flexible Manufacturing System
FTL	Flexible Transfer Line
IC	Integrated Circuit
ITRI	Industrial Technology Research Institute (Taiwan)
JIT	Just-in-Time
JMTBA	Japanese Machine Tool Builders Association
KAIS	Korean Advanced Institute of Science
KAIST	Korean Advanced Institute of Science and Technology
KIMM	Korean Institute of Machinery and Metals
KIST	Korean Institute of Science and Technology
KOMMA	Korean Machine Tool Manufacturers Association
KOSAMI	Korean Society for the Advancement of the Machinery Industries
LDC	Less Developed Country
LSI	Large Scale Integrated Circuit
MITI	Ministry of International Trade and Industry (Japan)
MOST	Ministry of Science and Technology (Korea)
NC	Numerical Control
NIC	Newly Industrialising Country
NIF	National Investment Fund (Korea)
OEM	Original Equipment Manufacturer
RAM	Random Access Memory
ROM	Read Only Memory

SMIPC	Small and Medium Industry Promotion Corporation (Korea)
TNC	Trans-National Corporation
TQC	Total Quality Control
VLSI	Very Large Scale Integrated Circuit

EXCHANGE RATES

Japanese Yen (¥) = US\$ 1

1964-1970	.....360.00
1971	.....350.00
1972	.....302.00
1973	.....272.50
1974	.....291.51
1975	.....296.8
1976	.....296.55
1977	.....268.51
1978	.....210.47
1979	.....219.17
1980	.....226.75
1981	.....220.53
1982	.....249.05
1983	.....237.52
1984	.....237.52

Source: NMTBA, 1985: 194; NMTBA, 1986: 203.

Korean Won (W) = US\$ 1

1978	.....484.00
1979	.....484.00
1980	.....659.90
1981	.....700.50
1982	.....748.80
1983	.....795.50
1984	.....827.40
1985	.....868.50
1986	.....881.50

Source: Economic Planning Board, 1985: 65;
EIU, 1987b: 2.

Taiwan Dollars (NT\$) = US\$ 1

1963-1973	.....40.00
1974-1978	.....38.00
1978-1980	.....36.00
1980	.....36.02
198136.85
198239.12
198340.07
198439.60
198539.85
198637.86

Source: EIU, 1987c: 8-9.

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CHAPTER ONE

Introduction

This thesis is about the process of acquiring technological capabilities in the design and production of machine tools in Newly Industrialising Countries (NICs). The NICs are a group of countries whose state of industrial development has been considered intermediate between the under-developed Third World and industrially developed countries. East Asian NICs include Hong Kong, South Korea, Singapore, and Taiwan, and, in Latin America, Argentina, Brazil and Mexico.¹ The study concentrates on the acquisition of technological capabilities in the production of Computer Numerically Controlled (CNC) machine tools in South Korea (hereafter simply "Korea"). It also, more briefly, compares the technological development of Korea's machine tool industry with the development of the same industry in another NIC, Taiwan, and in an industrially developed country, Japan.

1.1 NICs, Industrialisation, and the Machine Tool Industry

While much of the initial rapid economic and manufacturing growth of the NICs occurred in labour-intensive, export-orientated, industries, several NICs have now moved into more technology- and skill-intensive industries, including the production of capital goods. In the case of Korea, textiles, plywood and wigs were major growth industries in the 1960s. In the 1970s, Korea commenced the development of heavy industries such as steel, shipbuilding and vehicle production, as well as the manufacture of more complex consumer goods such as video cassette recorders and microwave ovens. These industries have become central to Korea's growth and exports in the 1980s.

This study partly arises out of problems concerning the future prospects of Korea, and other NICs, in technology-intensive industries: their ability to sustain rapid growth and their prospects of escaping their present intermediate state to become fully industrialised countries. The machine tool industry is a legitimate focus for engaging with these questions; firstly, because of its strategic position in relation to the

development of other industries, and, secondly, because it is itself a technology-intensive industry.

The machine tool industry is a strategic industry because of its contribution to the technological development and productivity of many other industrial sectors rather than because of its quantitative contribution to industrial output. The industry supplies machinery used to manufacture capital goods and provides a large proportion of production machinery used to manufacture metal goods of all types. Through its supply of production machinery, it is an important channel for the transfer of new production technology and productivity improvements. The machine tool industry is also the major supplier of production equipment to the military sector, and, indeed, it is often because of its vital role in the military-industrial complex that it is given special attention by governments.

In one of the most influential accounts of the role of the capital goods industry in economic growth, Rosenberg argues that the existence of a "well-developed capital goods sector" is the major difference between an industrialised economy and an under-developed one. He believes that the ability of this sector to produce and adapt machinery to comply with the changing requirements of production in other sectors enables a country to absorb and diffuse new technologies. This, Rosenberg says, makes these economies "viable" and "sustainable". Furthermore, he suggests that "[i]ndustrial societies, through the role of their highly developed capital goods producing industries, have, in effect, internalized in their industrial structure a technological capacity which undertakes technological change and adaption almost as a matter of course and routine" (1976: 99). Rosenberg stresses that the ability to design and produce specialised machinery "constitutes an external economy of enormous importance to other sectors of the economy" (1976: 144). Because of the industry's strategic nature and these potential external economies, the machine tool industry has been promoted by governments of many industrialising countries, including Korea, and offered the protected status of an "infant industry".² Although it is, of course, possible for countries to rely on imported machinery, Rosenberg concludes that "this

expedient deprives them of a learning experience in the production, improvement and adaptation of machinery which may be vital to economic growth" (1976: 100). Thus, Rosenberg's view places the machine tool industry at the centre of any attempt to explain industrialisation and, in particular, the experience of the NICs.

It must be emphasised that the benefits and external economies that Rosenberg sees flowing from the existence of a machinery industry can only be realised, firstly, if an indigenous technological capability to design machinery is present as well as the ability to manufacture it, and, secondly, if the machinery industry is in close contact with the consumers of its goods so that technology and information can flow easily between them. The mere existence of an indigenous ability to manufacture equipment does not necessarily put machinery users in a better position than users in countries with no machinery production.

1.2 Korea's Technological Capabilities

Definitions of technology have centred upon the collection of the physical processes which transform inputs into outputs. Conceived this way, a technology may be enclosed in the form of production equipment and its operation: a product, and a set of blueprints. Loosely speaking, such conceptions treat technology as "hardware". However, in the present connection a far more useful notion is that of "technological capabilities" - the "software" without which physical technology is useless. Technological capabilities are a complex combination of scientific knowledge, engineering techniques, craft skills, tacit knowledge, and social relations.³ They are, therefore, the human and social resources which make technology work. A technology, conceived as hardware, may be traded or transferred as a commodity, but it remains useless without a matching set of technological capabilities. Technological capabilities may be roughly divided into two types: manufacturing capabilities, which are the skills, or "know-how", required to use a technology in the manufacture of a product or in the operation of a process; and design capabilities, which include a greater understanding of the operating principles behind the technology, or

"know-why", enabling technologies to be developed, adapted or created. There is, naturally, a considerable overlap between the two types of capabilities.⁴

The position of Korea with respect to the indigenisation of capabilities is problematic. Jacobsson's important study of the CNC lathe industry in Argentina, Korea and Taiwan concluded that some design capabilities had been acquired in Korea.⁵ However, he only considered one small sector of the industry - the manufacture of low-to-medium performance lathes. Furthermore, he discussed these capabilities only from the point of view of NIC lathe producers becoming more competitive on the world market, neglecting any links between the industry and other industrial sectors and the benefits these may be receiving from the machine tool industry. Among more general studies, Amsden and Kim's research (1986) concluded that some design capabilities were now present for a limited subset of products in Korea's machinery industry. Enos and Park (1988: 235) and Westphal et al. (1984: 291) both argued that, while Korea had acquired considerable capabilities in production (including machinery manufacture), few capabilities in product or plant design had been indigenised. Westphal et al. add a caveat to their conclusions, suggesting that the bias in Korea's capability acquisition stems from the "natural sequence according to which plant operation is learned before the capability for plant design is acquired" (1984: 291). Chudnovsky's study of the complex capital goods industry in Korea, Brazil and India concluded that

[B]asic design and, in some cases, even detailed design for complex capital goods are not yet mastered by leading producers in the countries studied. Accordingly, they suffer from a major handicap which affects their ability to fulfil their role as eventual generators of technological innovations (1986: 86).

Thus, Korea was widely perceived by analysts in the early 1980s to stand at a crucial stage in its industrial development. It had entered technology-intensive industries, including the machine tool industry, but still had inadequate technological capabilities to design these products. The absence of these capabilities was seen to have two implications for

Korea. Firstly, it meant that Korea still depended on foreign technology for its industrial growth and development. Secondly, as Chudnovsky has shown, the lack of these capabilities meant that the machinery industry was not supporting productivity improvements and product developments in other technology-dependent industrial sectors (1986: 86). Without acquiring these technological capabilities, Korea would not be able to sustain its future development in technology-intensive industries and become, according to Rosenberg's sense, a fully industrialised economy. If, as Westphal et al. suggest, it is a natural sequence to acquire design capabilities after production capabilities, questions concerning Korea's present position in this sequence must be asked. This thesis engages with such questions by considering in detail the development of capabilities within the machine tool industry in Korea and the links between Korean machine tool builders and users.

The thesis uses a case study of the machine tool industry to investigate Korea's attempts at acquiring the technological capabilities to design, as well as to produce, specific types of machinery. The leading questions informing the case study are:

- (i) Is the Korean machine tool industry beginning to indigenise design capabilities, and, if it is, how is it acquiring such capabilities?
- (ii) What is the relative importance of different learning methods, e.g., learning by doing, learning by copying, etc., in this process?
- (iii) What are the technological difficulties experienced in the build up of these skills? What are the non-technological factors which aid or hinder their acquisition, e.g., government policy, industrial structure?
- (iv) What relations are there between the Korean machine tool industry and user industries? What effects do these relationships have on the development of design capabilities and on the competitiveness of user industries?

There are two main specific findings from the case study: firstly, that Korea in the mid-1980s was indeed beginning to acquire design capabilities to complement its existing production capabilities, and, secondly, that the Korean machine tool industry was also beginning to provide its users with significant technological support, thus illustrating one of the major justifications for NIC promotion of that industry.

1.3 Methodology

The coherent study of the acquisition of technological capabilities must be an interdisciplinary enterprise; it requires the skills of the economist, the country and area specialist, the student of politics, and even the skills of the sociologist and anthropologist. It must also have a important place for those versed in the actual technologies involved, and the environment required for their successful operation.

In order to understand such processes as technology transfer and the acquisition of technological capabilities, it is simply necessary to understand the nature of the relevant technologies. They should not be treated - as they sometimes are - as "black boxes". If we understand the nature of the technology, we can break down the technological capability requirements for its use or reproduction into what may be called "skill" or "capability areas". What is the relative difficulty of acquiring capabilities in each of these areas? Which areas make the greatest demands on existing knowledge-bases? In what sequence do the different skill areas need to be acquired? Consequently, compared to many existing studies in development economics and technology transfer, this thesis devotes greater attention to the technology involved and to the technological capabilities required.

It would, however, be equally mistaken to limit any such study to a narrow technological focus. The machinery industry is, by its nature, intertwined with many other industries and institutions, relying on some industries for materials, parts and components, and on other industries to constitute a market for its products. The availability of inputs affects

the competitiveness of the machine tool industry's production. The type of market it supplies, and the technologies used within the market, influence its product strategy and, hence, its technological requirements. The role of government policy in the promotion and protection of the industry must also be considered.

The study itself is highly empirical and specific, based on fieldwork undertaken in the machine tool industry in Korea and other countries in 1985. The fieldwork deliberately concentrated on one sector of the machine tool industry, the manufacture of CNC metal cutting machine tools. CNC machine tools are controlled by a programmable microprocessor which is linked directly to sensors on the machine. These machines are produced only by the more technically advanced NIC firms; therefore, by limiting the study to this sector, only the leading firms were included.⁴ The introduction of microprocessor controls has also had an enormous impact on the technological skills required for the production and development of these machines. Consequently, the firms considered were in the process of indigenising new skills, and it was therefore possible to obtain a large amount of data on the methods and difficulties they were having in acquiring the relevant capabilities. Finally, CNC machines are the basic production machines around which more automated manufacturing systems are produced, and the role of machine tool manufacturers in the design and installation of these systems is also considered.

1.4 Thesis Organisation

The thesis is divided into two parts; the first part, Chapters 2, 3 and 4, considers technological development, machine tool technology, and the global machine tool industry, providing a detailed background to the second part, which contains the empirical work of the case study and the comparative studies.

Chapter 2 examines the process of industrialisation in greater detail. The debate over whether developing countries should make or buy

their machinery is engaged with, and justifications are assessed for infant industry promotion and protection. This includes a more complete description of the external economies available from the machine tool industry. A range of theories about the division of technological capabilities and the range of learning methods used to acquire them are described and evaluated. The relative advantages, disadvantages, and effectiveness of different learning methods are surveyed. In particular, this discussion addresses the alleged dangers of becoming too dependent on foreign sources of technology through the continued use of licensing agreements and direct foreign investment.

Chapter 3 describes the technological principles of CNC machine tools, permitting an appreciation of the capabilities required to design and produce these machines. Changes in machine tool design, construction, and operation accompanying the introduction of computer control are a central theme of this chapter. And the final section presents a comprehensive list of the capabilities required to design and manufacture both conventional and CNC machine tools. It is shown that the technological capability requirements for CNC production are more varied and complex than those used in conventional production.

Chapter 4 provides an overview of the world machine tool market and the special characteristics of the industry which supplies it. The description of the global industry shows how product strategy is directly influenced by the market sectors which are important to various national industries. This includes an analysis of changes that have taken place in the international leadership of the industry in the last twenty years, and the reasons why some nations have declined while others have improved their position. Particular attention is paid to the entry by some NICs into the international trade in machine tools and their product strategies.

The second part of the thesis deals entirely with material on Korea and the comparison of Korea with Japan and Taiwan. Chapter 5 provides an overall introduction to Korea's industrial development and the general growth of its machine tool industry, including an account of the Korean

government's extensive intervention in industrial development, the structure of Korean industry, and the role of Korea's educational and research institutes. As well as describing the growth of Korea's machine tool industry, this chapter documents the expansion of industries which are large machine tool users. This provides information on the industries which may benefit from their links with the machine tool industry and on the structure of the Korean machine tool market.

The next chapter mobilises data from the Korean case study. The data are analysed to show which technological capabilities have been indigenised and which have not. The most important learning methods used in the acquisition of these capabilities are described. It is shown that at present the Korean industry relies extensively on imported critical components. The entry by Korean firms into the production of these components is described and its significance considered. Finally, there is a discussion of the factors influencing Korea's acquisition of technological capabilities: government policy, the domestic market, the structure of the conglomerates to which some firms belong, and the purchase of foreign technology.

Chapter 7 assesses the development of the Korean machine tool industry in comparison to the experiences of the same industry in two other East Asian countries, Japan and Taiwan. Japan provides an example of a successfully developed industry, which grew rapidly in the 1950s and 1960s to become the largest machine tool industry in the world by the mid-1980s. An examination of this industry enables a range of comparisons to be made between Korea's experience and that of a neighbouring nation with a relatively recently matured industry. What lessons can Korea learn from Japan? The Taiwanese industry offers an example of an alternative development strategy and the effects this has had on its technology acquisition. Is Taiwan a model for other NICs to copy or to avoid?

The concluding chapter summarises the findings of the thesis in relation to: (i) analytic methods in the study of technology acquisition; (ii) the position of the machine tool industry within a machine-using

economy; (iii) the advantages and disadvantages for a machine tool industry of being strongly linked to a domestic defence industry; (iv) the role of government in industrialisation, and particularly in technology acquisition; and (v) the process of acquiring technological capabilities in general.

Notes

1. There are various descriptions and definitions of NICs. Harris considers them to be countries which "have experienced high growth of output in the sixties and seventies, sometimes but not invariably on the basis of expanded manufacturing exports" (1986: 9). Balassa's more quantitative definition represents them as countries with "per capita incomes between US\$1,100 and US\$3,500 in 1978, and where the share of the manufacturing sector in GDP was 20% or higher in 1977" (1981: xix). Along with the seven countries noted above, the following are sometimes also considered as NICs: Chile, Greece, India, Israel, Pakistan, the Philippines, Portugal, Spain, Thailand, Turkey, Uruguay, and Yugoslavia.
2. Infant industries are those promoted or protected by a country's government during their establishment and early growth. Without the introduction of government measures, these industries would either take many years to develop or would not develop at all. Infant industries are usually given such treatment because it is felt that the whole economy will benefit from their existence.
3. In this thesis the terms "capability" and "skill" are generally used interchangeably. Accordingly, the term "skill" is given a slightly broader and more consequential sense than is typical, but, as Chapter 8 will briefly indicate, there is some point in doing so.
4. These definitions have been adapted from discussions in Stewart (1984: 81), Molina-Fuenzalida (1987: 466-74), and Dahlman and Cortes (1984: 602).
5. Jacobsson's research has resulted in many publications covering broadly similar ground. For the most part, his 1986 book is used, since this is his most comprehensive publication. Other publications listed in the bibliography are referenced as appropriate.
6. Although only the technologically leading firms were included in the study, they accounted for a significant proportion of Korea's total machine tool output (47% in 1984).

CHAPTER TWO

Acquisition of Technological Capabilities

2.1 Analysing Development and Technology

Until the mid-1970s, studies of NIC and LDC industrial development were characterised by what might be called an "economic" paradigm. They typically emphasised the importance of economic variables, such as relative factor prices, paying little attention to the acquisition of technology or to the role of technical change.¹ In explaining NIC success, economists often used the theory of comparative advantage, which in these countries usually derived from the cheapness of labour used in the production of labour-intensive items, e.g., textiles and low-cost electrical goods. Although this theory explains the export success of NICs after entering a specific industry, it does not in any way account for the processes by which a country reaches this point nor does it satisfactorily analyse prospects for future growth. Fransman (1986c: 1376-77) discusses three further problems in relying on the theory of comparative advantage: (i) that the determinants of technical and productivity change are omitted; (ii) that a passive role for the state is implicitly assumed; and (iii) that the theory does not in fact explain economic growth in these countries.

Technology was not entirely neglected in studies of developing countries. However, attention to it was typically restricted to only two approaches. Firstly, the "appropriateness" of technology was considered. Analyses concentrated on the question of labour or capital intensity in production techniques. Theoretical work in this area assumed that there is a virtually unlimited choice in the combinations of labour and capital input required to produce a given item. Thus, having found the right combination of labour and capital for a certain production function, it was then purely a matter of using the technology and production techniques appropriate to that combination. While a number of options are theoretically possible, the technological determinists argue that, in reality, very few choices do exist in the form of technically efficient alternatives, and, therefore, that the choice of labour and capital mix for

any single production function is limited. Thus, to achieve the required combination of labour and capital inputs, the choice becomes one of industrial composition rather than of technique (Stewart and James, 1982: 1-2). The second approach focussed upon the transfer of technology. Technology was treated as an item belonging to the industrialised countries which was transferred to passive developing countries (Lall, 1982b: 6). These studies concentrated on the high cost and difficulties of technology transfer, and the ensuing dependency of developing countries on industrialised countries for new technology. Yet both of these approaches neglected to study the processes by which indigenous capabilities are built up together with relevant knowledge and skills. And when such processes are studied in detail, the picture of developing countries as wholly passive and dependent is seriously undermined. As a result, the credibility of dependency theory itself has been eroded.

In the mid-1970s, a different approach to the study of development emerged; this approach, far from neglecting technology, concentrated on the build up of skills and capabilities in industrialising and developing countries themselves. This newer approach entails a change in point of view. Whereas traditional studies saw development in terms of economic variables, the new tendency has been to see development from the micro-level and from the perspective of the firm in the process of acquiring technology. How do individual firms acquire technological capabilities? What factors influence this acquisition? Of particular importance was the work of Katz (1978a, 1978b, 1984; see also Dahlman and Fonseca, 1978) on the development of indigenous capabilities in the Latin American steel industry, and the improvements in process engineering and techniques which had been enabled by these capabilities. Thus, firms in industrialising countries were no longer seen as passive users of foreign technologies but active adapters and developers of new technologies. Similarly, Lall (1980, 1982a, 1987, and especially 1982b) examined the growth of technological capabilities in industrialising countries, focussing on their exports of technologies to other countries.² Nevertheless, there still does not exist a wholly satisfactory understanding of the process of technology acquisition and the build up of technological capabilities. In particular, there is a gap in the

understanding of the factors which influence and affect the process - in developing, industrialising, and industrialised economies. This thesis is a contribution towards the further analysis of this process.

This chapter poses and responds to three quite general questions concerning the acquisition of technological capabilities and, in particular, those associated with the machine tool industry in NICs.

(i) What benefits accrue to a developing country, and to its manufacturing industry as a whole, from the establishment and promotion of an indigenous machine tool industry? What are the costs of doing so? (ii) What methods of learning have been used to acquire the relevant capabilities? (iii) What sorts of factors, both internal and external to individual firms, bear upon the development process?

In answering all these questions, the importance of types of interaction is stressed. The benefits of an indigenous machine tool industry flow from its ability to interact with the rest of manufacturing industry and the technological support it gives to other industries. The learning methods which appear most efficient similarly proceed from the interaction between machine tool makers, users, component suppliers, and competitors. And, finally, among the internal factors which bear most significantly upon the acquisition of technological capabilities is the place of a firm within a business structure which facilitates its interaction with machine tool users.

2.2 The Role of the Machine Tool Industry in Industrialising Countries

The introductory chapter noted the critical and strategic nature of the machine tool industry in an industrial (machine-using) environment. Its major input to other industries stems from its supply of production machinery and its diffusion of new production technologies over many industrial areas. All machine-using industries require new or modified machinery in order to introduce new products and enhance productivity. They are, in this way, dependent upon machinery producers. Many of these newly adapted or developed machines may then be utilised in other user industries, as well as in the original initiating user industry.³ This section examines the role of the machine tool industry in a machine-using economy. Why and when does an industrialising country need a machine tool industry? What precisely are the benefits of an indigenous capability in the manufacture of machine tools? To what extent and, importantly, at what cost is it thought that development of these capabilities should be promoted? Finally, which types of machines is it considered necessary to manufacture domestically?

For industrialising countries, the import substitution of consumer durables is often the first step in the development process, followed by the expansion of low-technology exports. Datta Mitra (1979: 4) points out that these countries are then caught at a crisis point: sustained economic growth, based on the import substitution or the export orientation policies of the government, is followed by a fairly rapid rise in the wealth of the population, a greater demand for more consumer goods, and an increase in wage rates. Unless these wage increases are balanced by a corresponding rise in productivity, the industrialising country will soon face severe competition in its export markets from other newly emerging exporters, which have the benefit of even lower wage rates. Thus, to remain internationally competitive, industrialising countries must either improve their productivity to retain their export market share or they must enter new markets.

One way to sustain the development process is to deepen industrial structure. This may be accomplished by increasing the range of goods

produced, expanding into more technology- and skill-intensive manufacturing, and reducing the country's reliance on a narrow range of export goods. There are two principal directions in which deepening can occur: the country can enter either the manufacture of previously imported materials, parts and components, or the manufacture of production equipment itself. Production of many of the goods exported by industrialising countries relies on the import of materials, parts, components, and production equipment. Raw material production facilities, such as steel works and petrochemical plants, can be economically established after the commencement of the industrial activity which has created a domestic market for these goods. For most industrialising countries, machinery and equipment form a large share of their total import bill: in Korea in 1977 they accounted for 27% of that bill (Datta Mitra, 1979: 2). At the extreme, Patel suggests that if the requirements for machinery, which increase with the expansion of industrial activity, continue to be met by imports, eventually there will be a crisis caused by a shortage of available foreign exchange. This crisis would, in effect, halt the development process (1983: xiii). If Patel is right, backward integration into the capital goods sector therefore represents not only an opportunity for import substitution in the NICs, but a financial imperative for industrialisation to continue in the long term.⁴

Datta Mitra (1979: 1-4) observes that for middle-income countries, such as Korea, Brazil and Mexico, production of final and intermediate goods had reached a high enough level that there was sufficient local demand to justify backward integration into capital goods production. Additionally, as these countries needed to move from labour-intensive to skill- and capital-intensive industries, the machinery industry, by virtue of its skill intensity, was appropriate. Finally, he argued that as industrialised countries started to protect their domestic markets against the traditional NIC exports of textiles, footwear, etc., NICs needed to restructure the composition of their exports. As the capital goods sector was unprotected and skilled labour intensive, this sector provided a logical option for development.⁵

Nevertheless, new market opportunities and purely financial considerations are largely peripheral to the main inherent value of an indigenous machinery industry. This arises from the ability of the machinery industry to support the technological development and competitiveness of other machine-using industries. This technological support includes the enhancement of productivity in user industries, the acceleration of the general diffusion of new technologies, and, eventually, the facilitation of "new" product introductions by user industries. The local availability of machinery suppliers enables the utilisation of the skills and knowledge of machine producers in the operation and enhancement of machine users' plants. This support function is crucial and cannot be stressed enough in the present study.

Such user take-up of machinery producers' capabilities can only occur if there are close linkages between the two types of firms. Lall (1980: 204) defines these linkages as "direct relationships established by firms in complementary activities which are external to 'pure' market transactions". These non-market linkages between buyer and seller can take many forms and are established for different reasons. In some cases, links may be made to ease the direct buyer-seller market relationship by reducing uncertainty and creating goodwill. This includes such actions as giving information to suppliers on anticipated orders or requirements so that they can plan their production accordingly. For the machine tool industry and its users, the main benefits of inter-firm linkages are technological.⁶ This type of link includes technical assistance and the exchange of information, ensuring a matching of needs and facilitating innovation.

A major use of the skills generated in the production of machine tools is in the maintenance and repair of existing machine tools and other machinery. Such skills are a necessity in any machine-using economy. If they do not exist, the costs of utilising complex imported machinery are extremely high, and the efficiency of these machines may be considerably reduced. Such skills can be deployed to extend the useful life of machinery, thus contributing to further capital savings which may be a particularly important consideration in NICs and developing

countries. Datta Mitra (1979: 9) notes that these skills are also of benefit as they increase the range of machinery that can be imported and maintained using indigenous skills. Furthermore, as Rosenberg (1982: 271) has shown, increased knowledge in the operation and performance of machinery should improve the knowledge-base on which decisions to import specific machinery are made. This has two consequences: (i) the NIC firm is able to negotiate with the seller from a position of knowledge of its exact needs, and (ii) machinery more appropriate to the needs of the country will be imported. Rosenberg refers to this as the ability to make an "intelligent choice" and suggests that this knowledge-base is very difficult to build up if there is no domestic experience or production capacity. Machine tool producers also acquire capabilities in the installation of production facilities and plant layout, which may then be applied in all sectors of manufacturing industry. These capabilities can be used to improve existing plant layouts and to install imported specialised machinery.

Technical and developmental support given to machinery users by the machine tool industry can also influence their overall competitiveness. This type of support may either be in the development of new production machinery to manufacture completely new products, or, more commonly, in the form of improvements to existing machinery and its operation/layout, enabling an increase in productivity. Both these mechanisms can considerably enhance the competitiveness of users in the domestic and export markets. Indeed, the loss of such a technical support network is now of great concern to the US vehicle industry, which increasingly relies on imported machinery to meet its requirements. One of the purchasing managers in General Motors noted that their dependence on imported machinery caused a considerable delay in their installation of new equipment compared to producers in countries with an active machine tool industry: "if you buy the very best from Japan, it has already been in Toyota Motors for two years, and, if you buy it from West Germany, it has already been in BMW for a year and a half"; "it is in GM's own best interest to foster its domestic vendors. Only with suppliers on the leading edge can GM gain an edge in production over its Japanese and European competitors" (American Machinist, Jan. 1986: 45). For most

industrialising countries, consideration of this leading-edge technological support from its machine tool industry is a requirement for the future. However, a domestic industry may enable the production of machinery more appropriate to the needs of users in these countries, rather than obliging them to accept the technological standards set down by producers in industrialised countries.

The technological benefits of domestic inter-firm links are not uni-directional; no links would ever be created if this were the case. Along the channels which exist between machine tool producers and users, there is also a transfer of technology and technological support from user to producer. The technological relationship between the machine tool making and using sectors should, therefore, be regarded as symbiotic. The initial development of capital goods production is dependent on the existence of a machine-using sector, as this sector provides machine builders with their domestic market. In the establishment of machine tool production, the users supply skills gained from the operation, basic repair and maintenance of machinery.⁷ Once established, the machine builders can give users technical support. However, users continue to transfer technology to builders during development and after maturation. Large machine tool users are usually acutely aware of new developments in their supplier industry, and they transfer this information to other suppliers. The new demand for specific types of machinery will also sometimes promote the entry of domestic firms into their production. Finally, the requirement for either new or adapted machinery entails the transfer of technological details and quality control specifications from user to producer. While it is often said that a healthy machinery industry contributes to a healthy economy, the reverse is equally true: a healthy user industry contributes significantly to a technically progressive machinery industry.

Although some of these linkages could be built up with foreign machinery suppliers if the machine tool users continued to rely on imported machines, this process would not only be very slow but it would also have many costs and disadvantages. The distance between user and producer means that regular or frequent contact is difficult to achieve,

and, consequently, the solution of minor machinery problems would have to be undertaken by the user and not the producer. Such solutions may be sub-optimal due to an incomplete understanding of the detailed technology incorporated in the machine. Repairs take longer because of the time taken for a technician to arrive on site and for any new parts or components to be delivered. Such delays are expensive, as they mean that machines may be inoperable for a considerable length of time, and they can also disrupt production of an entire unit or plant if the machine manufactures a critical component.

Machine tool producers will, of course, design special machinery or adapt existing machinery for all their users, including their foreign buyers. However, the industrialising or developing country user, as a small and infrequent buyer, will probably go to the end of the producer's queue. Furthermore, without a precise knowledge of operating conditions and requirements in the user country, the machines may not be suitable for the job for which they were intended. Indeed, many machine tool producers are now in the business of supplying and installing Flexible Manufacturing Systems (FMSs), which by their nature (see Chapter 3) entail a close working relationship between producer and customer. Accordingly, the export of such systems is a difficult matter. As industrialising country firms become more competitive on the world market, improvements to their manufacturing methods and enhancement of their productivity become more important. Given linkages only with foreign producers, such improvements are difficult to achieve, and, when they do occur, take much longer than for direct competitors in countries with such a support mechanism. Finally, in this competitive position it also becomes important to firms not to reveal their new manufacturing methods, so that they can gain a lead over direct competitors. If new machinery has to be imported, this not only involves time delays, but a greater risk that competitors in the export market will be able to purchase the machine quickly and reduce any technical or market lead open to the innovative firm.

2.2.1 A Role for Government?

Because of the range of technological and commercial benefits which can accrue from an indigenous machine tool industry, it is frequently regarded as suitable for "infant industry" support by NIC governments.⁸ Government policies intended to encourage the establishment and growth of such industries are designed around the protection of the domestic market and the subsidy of indigenous production. (The specific types of measures introduced by NIC governments to promote machine tool production are discussed in detail later in this chapter and in Chapters 6 and 7.) The establishment of a machine tool industry should, in principal, be beneficial to all sectors of industry and to all sizes of firms.⁹ However, in some cases national machine tool industries are promoted by government solely because of their specific technological and production support of the defence sector. In these cases, benefits to other sectors of manufacturing industry still accrue, but, because of the emphasis on the production of machines to defence specifications, such benefits may be limited.

For all the undoubted importance of government measures, a machinery industry may still develop without government support through an evolutionary process. This form of development usually takes place by the backward integration of large machinery users into in-house production for their own requirements, and by the growth of small repair shops which start making machines similar to those they repair, usually by direct copying. Traditionally, textile machinery producers often took up machine tool production, while, the Korean case study shows that, several vehicle producers have developed their own capabilities because of the direct benefits they consider they will receive. However, from the point of view of a government of an industrialising country, such evolutionary development may have unsatisfactory features. Firstly, it takes much longer for the emergence of a technically capable industry which can support production facilities in other industries. Indeed, it may never reach this point since it may not be able to sustain its slow development. Secondly, when the backward integration of large machinery users occurs, their main concern is to support their own production. Such

producers may be unwilling to establish links with competing firms and slow to establish links with firms in other industries.¹⁰

Discussing Korea, Brazil and India, Chudnovsky et al. (1983: 102) claim that "[t]he development of the capital goods sector in the three countries could not have taken place without explicit government policies aimed at fostering the domestic manufacturing of capital goods". In other words, they consider that environmental and market conditions would never have been sufficient to stimulate the evolutionary development of a capital goods sector. The case study of the Korean machine tool industry in Chapter 6 shows the undeniable importance of government intervention in accelerating the acquisition of technological capabilities and enhancing user-producer links. Nevertheless, contra Chudnovsky et al., it appears quite plausible that a machine tool industry would have developed through the backward integration of vehicle producers and increased domestic demand.

So far, only the benefits of an indigenous machine tool building capability have been considered, and it has been assumed that these will accrue automatically. But it must be stressed that the domestic production of machine tools does not necessarily mean that other indigenous production industries will benefit. In order for these benefits to be realised, the machine tools manufactured must meet domestic demands as to type, size and quality; linkages must form between users and producers; and the machine tool industry must acquire technological capabilities adequate to support its user industries and to solve their production problems. (Capabilities and their acquisition are considered in greater detail in the next section.) Secondly, the complete import substitution of all machinery imports, or even all machine tool imports, would be economically inefficient. In fact, no industrialised country is totally self-sufficient in machine tool production. The governments of some NICs have encouraged production in those sectors of the machine tool industry in which they consider that the benefits from an indigenous capability may outweigh the costs. Specialisation in these sectors is therefore often seen as desirable.¹¹

Little (1982: 240-50) has questioned the validity of the argument that the capital goods sector should be given special promotion in NICs, contending that the costs are too great and that NIC production in this sector is likely to be inefficient. He considered that, although developing countries and NICs have a comparative advantage in some areas of capital goods production, the production of capital goods is not, by itself, a sufficient condition to promote technological development and innovation. Little gives four reasons for caution in the promotion of the capital goods sector: (i) for most LDCs the development of an indigenous capital goods capability is a long-term goal and should not be aimed at prematurely; (ii) there may only be a minimal contribution from this sector to a more egalitarian and labour-intensive development; (iii) the transfer of technology and know-how is especially difficult in engineering industries; and (iv) there may never be any reduction in the dependence on foreign designs and innovations. Accordingly, Little argues that most of the capital goods produced in industrialising countries are copies of designs from industrialised countries; thus, indigenously produced capital goods are no more appropriate to the demands of an industrialising country than imported ones. However, while pointing out all the difficulties in entering such industries and the high costs associated with them, Little does not consider the substantial problems which flow from a decision not to enter. Firstly, if an industrialising country does not enter the capital goods or machinery industries, it will never be able to support its own development, and it will always have to rely on inefficient industries and imported technology. Secondly, although Little accurately stresses that production does not guarantee long-term technological development, he does not consider that there may be other potential benefits from production and from the inter-firm linkages which may be set up.

Although the lower labour costs of NICs and developing countries have been identified as giving them a competitive advantage in the capital goods sector, Pack (1981) questions that claimed advantage. He shows that levels of productivity are often much lower in developing than in industrialised countries, thus nullifying any cost advantage gained through the lower cost of skilled labour. Sources of low levels of

productivity in developing countries are numerous, a major problem being the lack of investment in production machinery and tools. Productivity is further lowered by poor plant layout, low capacity utilisation, inadequate training, and lack of information on machinery performance and operating parameters. Losses therefore occur not only in the inadequate use of machinery but also in inefficient use of skilled labour. Pack generally supports the idea that there can be growth potential in the mechanical engineering sectors of industrialising countries, and recognises that success in such sectors depends upon greater attention to machinery design and production. However, he warns about the risks and costs of expanding into high-technology areas. He suggests that industrialising countries should not expand into industries in which production technologies require high levels of scientific training or into those in which the product is undergoing very rapid design changes. In Pack's view, the production of standardised components, such as gears and bearings, is an achievable and appropriate goal for firms in industrialising countries. For these products, increased experience in production and quality control is necessary, but there are few demands for design skills.

Nevertheless, Pack's recommendations carry a cost for the industrialising country. While such a strategy may be successful, by increasing production capabilities and improving production management, expansion into such areas will not benefit other industrial sectors. Pack also suggests that such components production may also provide a source of export earnings. Indeed, there are such cases; for example, both Korean and Indian firms have exported cast-iron machine beds to firms in industrialised countries. But where these exports have taken place, they were at the specific request of the purchasing firm which sub-contracted the production. Without some form of help, either from foreign buyers or, alternatively, from government, it will be very difficult for the industrialising country firms to enter foreign markets with these products, and any export earnings from them will probably be small.

Without doubt, there are considerable potential problems in the development of a machinery industry by industrialising countries.

Nevertheless, governments in such countries have encouraged and continue to promote their indigenous industries. How, as a practical matter, can governments assess costs and benefits? Such calculations are in principle so complex that, in practice, they may be treated as impossible. Their difficulty is increased by the importance of what are usually called non-economic factors, such as those involved in military or nationalistic considerations. Jacobsson calculated the direct costs of promoting the machine tool sector from governmental fiscal measures introduced in Argentina, Korea and Taiwan, but did not consider the benefits from their establishment. He suggested that because Taiwan has a much higher export level, its benefit-to-cost ratio was higher than Korea's (1986: 208). Significantly, the benefits of a technological capability in machine building, if it is adequate to support other industries, were not included. (Remarkably, these benefits were, in fact, proposed by Jacobsson as one of the reasons why governments should support the development of a machine tool industry (1986: 209).)

Such benefits are probably impossible to quantify. While it is possible to measure the reduction in installation costs on major projects, the potential savings from being able to make a better choice, the faster repair of machinery, and the design of specialised machinery are more difficult to estimate. However, for long-term development, the absence of these skills may entail very high costs for other manufacturing sectors, originating from dependence on foreign machinery and inability to improve existing equipment or install new plant. While the initial costs of establishing and promoting the machinery industry may be high compared to its short-term returns, the long-term costs of not having capabilities in this industry are potentially even greater. The cost-benefit calculation is, of course, very different if the machine tool industry is promoted especially to support defence production. In these cases, national security is the highest priority, and the high costs of initiating a machine tool industry may be considered small in comparison to its ability to support the domestic defence industry. Moreover, once the machinery industry has been initiated for predominantly defence considerations, the cost environment for a civilian sector may be substantially affected.

Of course, for some countries the potential benefits of an indigenous machine tool industry may never outweigh the associated costs of its promotion. This is true for countries with either a very small manufacturing industry, such as New Zealand, or those, such as Denmark, which have easy access to machine builders in other countries. In these countries, the domestic machine tool market is too small to be able to support an economic domestic industry, and they have few export possibilities because no competitive export advantage exists.

For those countries in which there is either a large enough domestic market to support an indigenous industry or in which there is a competitive advantage in machine tool production, the main question is: in which areas should production be concentrated? This is really a question about specialisation, which is crucial if the machine tool industry is to become economically viable. Rosenberg argues that specialisation should be seen in a dynamic as well as a static framework:

[T]here is an important learning process involved in machinery production, and a high degree of specialization is conducive not only to an effective learning process but to an effective application of that which is learned (1976: 17).

The preferred direction of specialisation is a decision which depends upon a variety of considerations. What capabilities are required to manufacture different types of machines? What is the nature of the domestic and export markets for various machines? (These considerations are dealt with in Chapters 3 and 4.)

To summarise, there are three major reasons why governments of industrialising countries may consider the establishment of an indigenous machine tool industry to be beneficial: (i) the machinery produced may be more suitable for operating conditions in these countries; (ii) the externalities of machinery production are of benefit to all sectors of manufacturing industry; and (iii) the indigenous manufacture of capital goods offers potential savings in foreign exchange requirements and can contribute to an increased rate of domestic capital formation. Of these factors, it has been shown that the potential externalities from the

technological capabilities formed in the machine tool industry, and its technical linkages to other industries, are essential requirements if a country is to become fully industrialised and able to introduce its own new products. Because of these important benefits to other sectors of manufacturing industry, and because the natural evolution of a machine tool capability may take a long time, governments in industrialising countries have concluded in practice that the costs justify the benefits. Although governments of industrialising countries have taken a variety of positions on import substitution and protection of their machine tool industries, a strong case can be made for the advisability of specialisation. Such a case would argue the appropriateness of specialising in those areas of production whose capabilities are of the greatest benefit to domestic industries and in which some competitive advantage may be secured.¹²

2.3 Technological Capabilities and Learning Methods

In order merely to sustain the development of an indigenous machine tool industry a certain range of technological capabilities are required. (Indeed, Bell et al. (1984) argue just this case for any infant industry.) However, for the machine tool industry to effectively contribute to the development of the manufacturing sector in general, a greater range of capabilities is needed. There is no necessity that a national machine tool industry will acquire that greater range of capabilities. The Taiwanese machine tool industry, to be discussed in Chapter 7, is an export-orientated industry with a limited range of technological capabilities, contributing little to other Taiwanese manufacturing industries. That situation has developed as an historical outcome of a structure in which there has been relatively few inter-firm linkages between machine tool makers and users. Yet in other countries, such as Japan and Korea, a far greater range of technological capabilities have built up in the machine tool industries, and these have proved an important source of technological support for the whole manufacturing sector. And, as Chapters 6 and 7 will show, that situation developed as an historical outcome of situations in which inter-firm linkages between machine tool makers and users have been many and close.

In the previous chapter, technological capabilities were defined as a complex combination of formal and tacit scientific knowledge, engineering techniques, craft skills, and social relations; and the development process was considered as the continuous accumulation of such capabilities. Technological capabilities were broadly divided into two types: those which required "know-how" and those requiring "know-why". In this section, technological capabilities are examined in greater detail. How have capabilities been categorised? How are capabilities acquired or enhanced? What forms of learning mechanisms operate in industrialising country firms, and which are the most effective methods of quickly assimilating technology? How can capabilities be measured?

2.3.1 Types of Technological Capabilities

Perhaps the most comprehensive categorisation of technological capabilities is that of Dahlman and Cortes (1984), which identified five broad and overlapping categories of capability required for setting up and operating manufacturing facilities: (i) The ability to acquire existing product and process knowledge. This includes the ability to search for technology, select that which is most suitable, and negotiate the terms on which it is transferred. (ii) The implementation stage, i.e., the ability to install and commence the operation of technology. (iii) The ability to operate established production plants, including the skills required to operate the plant, and to repair and maintain production equipment. (iv) The capability to adapt, adjust and improve production equipment, raw materials used, or the final product, in order to remain competitive. (v) The ability to create new technological knowledge in either the product or the production process, in order to adapt them to local conditions or to operate more efficiently.¹³

The ordering of the capabilities should not be seen as stages of development nor is one capability a prerequisite for the next. As Lall (1987) points out, not all these capabilities have to exist within each firm, or even within the industrialising country, for it to undertake manufacturing activities, but it has to be able to buy in the capabilities it does not have. For example, few industrialising countries have the capabilities to install large plants, especially if this is their first experience in a specific industry. In these cases, new plant may be acquired on a turnkey basis, i.e., a complete plant is bought, which is installed and commissioned for them by the vendor. Alternatively, foreign consultants may be hired to supervise installation. However, each firm must acquire a basic repertoire of capabilities:

[T]here are certain core technological activities which have to be provided by the enterprise itself - they define the boundaries of the firm itself as a distinct economic entity. The ability to select the right project and source of technology, to provide efficient day-to-day plant operation, to make necessary adaptations, to select and induct new generations of technology - these cannot be bought in (Lall, 1987: 12).

These "core" technological activities are mainly based on product and production "know-how", and there is only a small requirement of "know-why" necessary in the choice and introduction of new technologies. However, if the firm is going either to make major adaptations to the product (or production equipment), or if it wants to develop its own new products, there is an increasing need for a greater understanding of the product/production equipment. That is, the firm needs a greater amount of "know-why" to undertake such developments. This is especially important for the machine tool industry. Only with a considerable knowledge of machine tool design and construction can firms undertake their support function described earlier. (In the following chapter, the specific technological capability requirements for the manufacture and design of machine tools are examined, including an analysis of the additional capabilities required by conventional machine tool producers commencing CNC machine tool production.)

As product and production technologies are continually changing, the acquisition of technological capabilities, or, in later stages, the process of innovation, are also continuous. Consequently, new choices have to be made about the expansion or installation of further plant, and the introduction of different technologies and production methods. At each stage, the ability to search for new technology and to negotiate its acquisition will make subsequent technology acquisitions easier. Once experience in the installation and operation of similar plant has occurred, firms' ability to make an intelligent choice is enhanced.

2.3.2 Learning Processes in the Acquisition of Technological Capabilities

National industrial development depends on the build up of technological capabilities, usually within firms, or in technological institutes or universities. How are these capabilities learnt? Lall suggests that "lllearning is based partly on the experience of production, partly on importing 'ready made' knowledge from industrialized countries and partly on a deliberate process of investing in the creation of

knowledge" (1987: 230). Lall thus offers a useful initial breakdown of different types of learning, and these categories may be used to examine in greater detail the extremely wide range of learning methods that firms use to acquire new technological capabilities and to enhance existing ones.

(a) Learning from Experience of Production

This type of learning is often referred to as "learning by doing", and has traditionally been regarded as a learning process which is both automatic and costless. Bell et al. (1984) have strongly argued that learning by doing is not costless, and, unless there is considerable technological effort incorporated in this learning process, it is also likely to be ineffective. They argue that learning in production only occurs if there is a feedback of information, enabling an understanding of the production process, and a flow of information which can be used to improve the productive system. This gathering of information and its transfer only occurs if there is a deliberate "allocation of resources to an effort that can generate, interpret, and act upon that flow" (1984: 120). To illustrate this point, Bell et al. cite Dahlman and Fonseca's (1978) study of technological change in the Usiminas steel plant in Brazil, where the introduction of a standard cost system initiated the feedback of information on plant performance. By monitoring the system in this way, knowledge of the factors behind variations in performance and a more thorough understanding of the system was built up. This increased knowledge was then utilised to identify problem areas and to implement improvements. Although this type of learning can be used to make considerable improvements in productivity, Bell et al. think that firms cannot rely only on this type of learning in order to continue developing. If the firm is to achieve and maintain international competitiveness, it must supplement this method with direct training and with investment in new technologies.

(b) Learning by Importing "Ready Made" Knowledge

There are numerous methods by which firms in developing countries acquire technology from industrialised countries, and, in their early development, learning processes which can accompany the import of technology are probably the most important source of technological capability expansion. It should be emphasised here that the importation of technology does not imply that there is little technological effort on the part of the importer; indeed, as in the case of copying foreign products, the reverse may be true. Technology can be imported in many different forms: foreigners can be either active or passive in its transfer; and the actual transfer of the technology can be either formally regulated or informal. Table 2.1 shows different types of technology transfers, distinguishing between formal and informal, and the active or passive role of foreigners in each type of transfer.

Table 2.1 Different Methods of Acquiring Foreign Technologies

	ACTIVE ROLE FOR FOREIGNERS	PASSIVE ROLE FOR FOREIGNERS
FORMAL AGREEMENTS	Direct Foreign Investment, Joint Ventures, Purchase of Turnkey Facilities, Hiring Consultants, Licensing, Overseas Training	Machinery and Plant Imports
INFORMAL TRANSFERS	Feedback from Exporting	Crude and Adaptive Copying, Information in Journals, etc.

Adapted from Fransman (1985: 577)

There are various types of learning processes which accompany the different methods of technology acquisition. The types of capability built up are also considerably affected by the mode of technology transfer, and, when foreigners have an active role, the nature of their involvement.

Imported plant and machinery often incorporate technology which is new to the industrialising country. When these imports are standardised and fairly small in size, there may be very little contact with the foreign vendor. Although initially these imports may be used inefficiently, if active learning-by-doing occurs, its use should improve. The higher quality of new equipment may enable manufacturers either to increase their productivity or their product quality. (When the imports are on a larger scale or are designed especially for the purchaser, it is likely that the vendor will have an active role and this can be regarded as similar to the purchase of turnkey facilities.)

In many industrialising countries, the early build up of technological capabilities depends on copying imported goods, employing skills that have been built up through using the goods (for example, the small machine tool repair shop reproducing the machines it repairs). According to Chudnovsky et al. (1983), there are two distinct types of copying: crude and adaptive. Crude copying involves the simplification of imported goods, removing complicated parts, and reducing the manufacturing requirement. After the initial simplification work on the product has been completed, it is very easy for other firms to then reproduce the technology. Although this type of acquisition of technology and production does give the country an entry into the industry, Chudnovsky et al. show there are major limitations to the subsequent development of the industry and the build up of capabilities. Firstly, as the product is for the bottom (cheap) end of the market, prospects for improving the product while retaining its low price are remote, and any improvements will reduce the potential market share. Secondly, if any developments are undertaken, these may be subsequently copied, at little or no cost, by other domestic producers. Thirdly, as production is usually low volume and responsive to fluctuations in the level of demand, constraints are placed on the scale, and, consequently, on the standardisation, of production operation. Finally, because of the low quality of the product, there are few opportunities for expanding the market through exporting. Thus, there is little incentive for firms to attempt such developments, and there may be considerable risk involved.

When the copying process is accompanied by the adaptation of product design to improve quality or marketability (or both), this can be considered adaptive copying. For a firm to undertake adaptive copying, a greater skill level and a greater depth of manufacturing experience are required, i.e., adaptive copying also requires an element of "know-why" as well as "know-how". Chudnovsky et al. (1983) suggest that a firm's size affects whether it is able to allocate adequate resources to adaptive copying, and they conclude that larger firms may be the only ones able to undertake it. As with crude copying, other factors, such as the availability of cheap machinery and the nature of the domestic market, also affect producers' ability to enhance product design.

All copying activities have associated costs. The original product being copied usually has to be purchased. And the time taken by engineers to learn about the product, reproduce it, and refine either the product or its production all have associated costs. Crude copying may be regarded as a fairly low-cost activity, while the costs associated with adaptive copying are greater since they incorporate a continuing technical effort and investment. Once a successful copy has been made, there are no further costs, such as those involved when a royalty still has to be paid to a foreign licensor. Furthermore, if there is a potential export market, unless the copied product has directly infringed a copyright or patent, the manufacturer has the chance to exploit these opportunities. Manufacturers using foreign technology agreements frequently have their exports limited or regulated as part of such agreements.

If a firm commences production using some form of copying, is this method sufficient to build up enough design and technical skills to become fully competitive on the international market? It has already been shown that there are limits to technology acquisition through crude copying. Chudnovsky et al. (1983) claim that firms relying solely on imitation will reach a limit of technical ability and will be unable to progress further without help from some outside agency. Bell (1984) reaches similar conclusions and suggests several different learning mechanisms which may be used to overcome these problems. "Learning by hiring" may be one such effective method. However, to be able to buy in

the appropriate knowledge and skills, they have to be readily available, and this is not always the case. Existing personnel may be trained either by sending them abroad to learn new techniques in established plants or by hiring foreign experts to work in the plant and train new workers on site. Specific gaps in knowledge and skills may be filled by hiring consultants or by working with a research institute. This kind of learning is referred to as "learning by training", and in many cases it involves more formal participation by foreigners. While this type of learning can accompany the formal transfer of technology, it does not necessarily do so. For example, students from an industrialising country studying in more developed countries return with considerable skills and knowledge, yet there is no direct transfer of technology as usually understood.

There can be considerable capability development accompanying the formal import of new technologies or techniques. There are three distinct types of technology that can be included in such agreements: (i) basic product design; (ii) detailed design of parts and components; and (iii) manufacturing technology. Licence and co-production agreements vary as to which of these technologies are contained, and the depth of design and production know-how and methodology transferred will also be specific to the agreement. The whole technology package is incorporated, with some provision for training, in joint ventures and the installation of turnkey plants.

Depending on the form of agreement and the technology transferred, there will be different emphases on the types of capabilities built up. With joint ventures and direct foreign investments, the technological capabilities developed tend to be concentrated in production and the repair and maintenance of plant and machinery ("know-how"). Little "know-why" is included, and few skills in product design or development are ever transferred, as this work is usually undertaken by the parent company in the developed country.¹⁴ Similarly, with the purchase of turnkey plants, the main capabilities acquired are in production, repair and maintenance. However, in many cases there is also a transfer of installation capabilities incorporating an element of "know-why". These

capabilities may be used in subsequent expansion projects and in the construction of new plant.¹⁵ Licensing agreements are probably most variable in the capabilities transferred, depending on their precise terms. In some cases, design skills are transferred, and personnel from the licensor firm are trained in the licensee's own plant. Some production capabilities may be transferred as well. Alternatively, the licence may only cover a small part or component of a larger product, and, if the licensor is already skilled in the manufacture of this product, the agreement is accompanied by only very limited learning.

The cost of acquiring a new technology is more than the cost of a set of blueprints, since the utilisation of resources in the transmission of the technology and in the absorption of technological capabilities must also be accounted for in the final figure. Teece (1977) lists four additional project costs, beyond royalty costs, incurred in the transfer of technology. These expenses are: (i) the cost of pre-engineering technological exchanges, so that the buyer understands the basic characteristics of the technology to be transferred; (ii) the engineering costs associated with transferring the product design and its production engineering; (iii) the R&D costs incurred in the installation and adaptation of the technology in solving unexpected problems and modifying the technology to suit local conditions; and (iv) the pre-start-up costs in de-bugging the system and training costs to enable the manufacture to continue as efficiently as possible. These are all one-off costs at the start of the agreement, but there are other costs which are continuous throughout the operation of the agreement. Established in the agreement will be a royalty payment as a percentage, usually between 2% and 5%, of licensed sales. There are also implicit costs built into the agreement and continuing through its life, including the tied import/supply of certain parts and components, export restrictions and grant-back provisions.¹⁶

The costs incurred within the firm in the acquisition of the technology will depend to a large extent on the indigenous capabilities which already exist. Both Chudnovsky et al. (1983) and Teece (1977) show that the existing technological capacity in the firm affects the success

of transfer. Greater technical knowledge will aid in the negotiation for the technology and in the conditions set out in the transfer agreement (referred to earlier as the capability to make an "intelligent choice"). Included in these conditions will be the training and technical assistance (i.e., the "unembodied" knowledge) to be transferred in the package. Moreover, the R&D capabilities of the firm are important in solving problems encountered during the transfer of the technology, and during subsequent modifications.

Firms in industrialising countries have been critical of many aspects of licensing agreements, and especially of the type and quantity of technology contained therein.¹⁷ The main criticism is that the transferred technology is often old and the transferors are unwilling to license any of their new technology. Thus, the licensees are unable to compete at the leading edge of the technology. A second criticism is that the information contained in the agreement does not cover the design methodology. This means that the undeveloped design skills in the licensee firms cannot be effectively enhanced or built up. The build up of design skills is therefore a very slow process and the new firms are, in effect, forced to rely on imported technology for longer.

The characteristics of the transferor are often neglected in analyses of technology agreements since it is assumed that one source will be as good as any other. Teece (1977) points out that the extent to which the technology and its response to different conditions are understood by the transferor is an important factor to be considered. As the technology matures, the transferor gains more knowledge of the effects of different parameters and changes in design. And there are other advantages of matured technology. Firstly, the design will be in a final form, which will make it easier to transfer and to understand. Secondly, if the technology is widely diffused, it should also be cheaper for the licensee, who can choose from whom he purchases the technology. These factors mean that new technology, which has not been widely tested and diffused, is difficult and hence costly to transfer, both for the licensee and the licensor.

Finally, there is the learning method known as "learning by exporting", discussed by Westphal et al. (1984b: 286). At first sight, this seems a rather odd inclusion in a discussion of learning by importing "ready made" knowledge, since it is not immediately obvious how the export of goods leads to an import of capabilities. Yet this import is just what occurs from the feedback of product information and technical help following the supply of export goods. Westphal et al. argue that this was an important influence on improvements made in both productivity and quality control in some Korean industries. This type of learning frequently took place when foreign purchasers visited the Korean producer and suggested changes in the production process and engineering. Although the flow of information is virtually costless for the industrialising country firm, there are costs associated with this learning method, since firms have to allocate resources in the implementation of suggestions and recommendations concerning the improvement of their product or production methods (Fransman, 1985: 579).

(c) Learning from Investment in Knowledge Creation

In order to be effective, the learning methods treated above necessarily involve some degree of investment in knowledge (or capability) creation. Indeed, Bell suggests that "[e]xplicit investment in technological capacity becomes ... a necessary condition for any further progress" (1984: 200). And, as noted earlier, Bell et al. (1984) have asserted that costless learning by doing does not create technological capabilities. Similarly, unless there is a dedicated investment in the learning processes accompanying technology imports of all kinds, whether foreigners are taking a passive or an active role, few indigenous capabilities will be acquired.

Nevertheless, firms and governments may take deliberate decisions to build up their knowledge bases. Investment in knowledge creation is important in the field of marketing and in the observation of technological trends in both the domestic and international markets. Bell (1984) refers to this type of knowledge creation as "learning by searching", for example, collecting information about technologies which

may not be acquired or which may only be acquired at a later stage. This process increases the knowledge-base on which future decisions about changes in product or production can be made, and, therefore, it can be an important input into the success of new technology imports. There are many ways that firms can acquire this type of information. Trade journals and periodicals are a common source, and, trade associations often publish their own journals, which contain information about general technological trends and, sometimes, synopses of new patents. Trade fairs, especially the larger international ones, are also an important opportunity for firms to increase their awareness of both technological developments and market trends. Governments, notably in Japan, have established centres to collect this type of information and disseminate it to industry.

The creation of design and development teams to work on specific new technical projects also represents a considerable investment, and commitments of this sort are usually made only after production has been established and firms have acquired some "know-why" as well as "know-how". These investments are not just made at the firm level: in a number of countries national institutes, funded totally or partly by government, have been established to support industrial development. Although much of the work undertaken by both these types of development groups frequently relies on technology imports, and they rarely undertake anything more than applied research work, they do represent a formalisation of technological endeavour.

(d) "Interactive Learning"

In addition to the three learning processes identified by Lall, there is another mechanism that appears to have been of great importance in the acquisition of capabilities by both Korean and Japanese machine tool firms. This mechanism is related to learning from experience of production, but it is embedded in the structure and dynamics of technical inter-firm linkages. The closer the links between producers and users, the more effectively both appear to learn from each other and to transfer capabilities. Learning through these links may be either through the

transfer of technical information from supplier to buyer, through the development of specific products at the request of the buyer, or through feedback on potential product improvements from buyer to supplier.¹⁸ In the development of specific products, there is frequently a considerable amount of technological information which is transferred between firms. Machine tool producers have considerably enhanced their own capabilities through the manufacture and adaptation of machines for their users. In addition, machine tool makers have benefitted from technological innovations made by their component suppliers, and from suggestions and feedback from users on the domestic market and on international markets. Because of the active role of both suppliers and users in this type of learning, it is best referred to as "interactive learning". This method of learning will be documented and illustrated in Chapters 6 and 7.

2.3.3 Measuring Technological Capabilities

When "technological developments" are referred to in industrialised countries, they are usually taken to mean the introduction of new products or processes. The technological creativity of firms in these countries can, therefore, be measured by an analysis of new products developed or the number of patents applied for. This type of measurement in industrialising or developing countries is largely meaningless. It is important to stress that indigenous technological capabilities in industrialising countries are rarely at the leading edge, or frontier, of relevant technologies. Consider, for example, Stewart's definition of indigenous technology:

I take [indigenous technology] to be a local capacity to create/adapt/modify technology. In other words, as well as the creation of some completely new technology, it includes the development of technology already known elsewhere and the local modification of imported technologies (1984: 81).

Thus, any measure of the increase in indigenous technological capabilities must include developments which enable the firm, or the industry, to move closer to the international frontier or which enable it to develop its own frontier. Such a measure would also cover the increase in capabilities

required to master and use all imported technologies. This definition of acquired capabilities is close to Nelson and Winter's view of innovation: they suggest that "almost any nontrivial change in product or process, if there has been no prior experience, is an innovation" (1977: 48).

Even with this much broader definition of what should be considered as an innovation and an increase in technological capabilities, there is still the difficulty of trying to measure both the level of technological capabilities within a firm or the increase in such capabilities. One indicator of the accumulation of technological capabilities is the change in direction of technology flow. While in the early stages of development a high proportion of technology is imported, as technology is absorbed and diffused imports decrease. The end result would be the achievement of technological mastery and the ability to develop new products/processes. Then, exports of technology can exceed imports. However, for countries still in the process of industrialising such a measure is not possible. Even for countries which are now considered to be industrialised there are still problems. Chapter 7 shows that in Japan the reversal of technology trade had not occurred by the early 1980s, because payments were still being made for agreements made several years earlier.

The ability to export technology can be used by itself as an indicator of technological capabilities, and indeed has been used extensively by Lall (see, for example, 1982b). Lall only includes exports of technology which are skill based, while excluding exports of commodities and equipment. The latter are excluded because they can be manufactured with few indigenous capabilities, for example, by assembling imported parts or with considerable foreign influence in a direct foreign investment firm. Skill-based technology exports do, however, indicate an accumulation of capabilities. Although this may be an adequate indicator for the build up of capabilities, it does not necessarily follow that countries lacking such technology exports have not reached high capability levels. Additionally, this measure can only be used to show the build up of certain types of capabilities. For example, capabilities

in the installation of equipment will be well represented, but capabilities in adapting, adjusting, and improving products will not.

Enos and Park suggest four different measures to indicate the absorption of imported technology (1988: 13). The first two concern the specific activities involved in the absorption of the new technology (e.g., the design of the plant and equipment, its purchase and installation). Reductions in the time taken for these activities to be completed and the increase in the proportion of the workforce originating in the importing country can both be used to show an increase in capabilities. However, neither are foolproof; activities may be terminated prematurely or a foreign expert replaced too soon, both of which would result in inefficiencies and increased costs. The other two measures apply to the actual production undertaken in any new venture. Both the rate of output compared to design capacity and the cost of output show increases in operating capabilities. And in industrial sectors where there is little product variation such measures can be effectively compared to show different rates of accumulation in various firms.

However, for the machine tool industry such a measure is extremely difficult because of the great variations in products and the capabilities required to manufacture them. For example, Chapter 6 shows that the design and production skills needed in the manufacture of machining centres are greater than those required for the production of CNC lathes. Quantitative comparisons are also problematic here. Comparisons of output are only indicators of firms' size and commercial success; they do not address the depth to which capabilities have been acquired. Thus, by relying on imported technology, firms can manufacture very successfully with very few capabilities in the design or adaptation of machine tools. Similarly, comparisons of the specifications of the products themselves give no insight into the origins of their design, the skill input of the firm, or the reputation of the machines on the market. Furthermore, as machines are designed for different markets, for different purposes, and, to cut to different tolerances, direct comparisons of specifications are probably useless.¹⁹

Jacobsson (1986: 105-09) ambitiously attempts to rank firms according to quantitative measures of their production and design capabilities. He bases his measure of design capability on five factors: the type of design, the origin of the design, the number of models produced, the number of designers and electronic engineers in the firm, and the establishment of a marketing network in the US. However, he admits that "[e]valuating the importance of the five factors that indicate the technological capabilities of the firms is problematical" (1986: 109), and proceeds to give a qualitative justification for his ranking.²⁰ Indeed, given the complex nature of the firms and their products it is highly doubtful whether any such quantitative typology can adequately indicate levels of technological capabilities. Any meaningful comparison, therefore, has to be qualitative and needs to take into consideration both the complexity of the products and the depth to which development, design and production capabilities have been absorbed.²¹ In order to undertake this sort of analysis it is necessary to examine in detail the technological requirements for the design and production of the machine tools studied. This is the task of Chapter 3.

2.4 Factors Influencing the Acquisition of Technological Capabilities

Firms' acquisition and development of technological capabilities, and the learning mechanisms they choose, are heavily influenced both by the make-up of the firms and the environment in which they operate. A broad "environmental" approach has been recommended by several analysts, notably Stewart. She also pointed out deficiencies in existing work which identified a range of causal factors and interactions between them but which said little about how these factors actually operated (1984: 93). In a similar vein Katz writes that "[a] point not yet explored in the recent literature is that both the rate and specific nature of the technological learning sequences seem strongly to depend upon nationality, size of company and general macroeconomic atmosphere underlying firm operation" (1984: 125).²² It is possible to divide influencing factors into two groups: (i) those which are specific to a particular firm and, therefore, may be considered internal to the firm, and (ii) factors which are industry or country specific and, therefore, external to individual firms. An important point to note is that a factor should not be treated in isolation, as each factor may interact and influence the others.

2.4.1 Internal Factors

Three internal factors can be considered here: (i) the size and organisation of the firm, (ii) its skill profile, and (iii) the other products it manufactures. All these factors affect the firm's knowledge of technology, the capabilities that have already been acquired, and the learning mechanisms that it can undertake.

(i) Size and Organisation

The number of employees in a firm, its turn-over, and its capitalisation affect its ability to expand, to acquire new machinery, and to enter new product areas. These factors primarily influence the firm's resources and, consequently, its capacity to take risks and invest in technological development. As already noted, Chudnovsky et al. (1983) suggest that size is an important factor when considering whether firms

are able to undertake adaptive copying. And the case study in Chapter 6 finds that size was also a particularly important consideration for firms wanting to enter formal technology import agreements. For small firms there are great difficulties in establishing overseas links and negotiating the terms of technology agreements, and, compared to larger firms which can draw on their own internal resources, they have much greater difficulties both in entering into formal agreements and in enhancing their technological capabilities. Larger firms are able to establish close links with foreign companies, negotiate effectively for the transfer of technology, and invest in training schemes and technology creation. Bessant (1983: 50) has suggested that although small firms are restricted in their access to finance and technical resources, their size enables them to react faster to market and technology changes. Similarly, Freeman (1974) thinks that smaller firms have an advantage in new product developments stemming from their flexibility, concentration and more efficient internal communications.²³ While such factors may have an effect on firms in an industrialised country, the Korean study indicates that small firms in NICs have much greater difficulties in approaching the technology frontier. And, because of their relatively low investment in capability formation, it takes them longer to build up a full range of technological capabilities.

When a firm is part of a larger company or industrial conglomerate, it becomes important to consider how it operates within that structure. Is the firm closely tied to other firms within the group? Are there close, collaborative technological links between firms in the group which manufacture similar products or which utilise similar technologies? Have these links "internalised" interactive learning? This is an especially important consideration for the machine tool industry. Firstly, some firms integrate backwards into the manufacture of machine tools in order to support the manufacture of their main product, typically vehicles. The production strategies of such machine tool firms, which sell a large proportion of their machines to a parent or sister company, will obviously be very different from those of independent firms which sell nearly all their machines on the open market. Secondly, since interactive learning seems to be an important mechanism through which firms build up their

capabilities, the internalisation of this mechanism may be a major influence on the development of some firms.

Firm organisation is also an important factor in the Korean case as the structure of its industry is slightly unusual compared to other NICs, proceeding from the existence of very large conglomerates, known as *chaebols*. In the 1970s, the *chaebols* dominated industrial growth and technological development. (Similar conglomerates, known as *keiretsu*, exist in Japan.) Membership of these large industrial groups may give firms several advantages over independent firms. These advantages appear to be an inherent part of the firm structure and did not arise solely because the *chaebols* were favoured by the Korean government in the industrial incentives it offered. The inter-firm linkages between companies within the same group can be very close, and may affect many aspects of their technical development. For example, conglomerate firms may have access to centrally- or jointly-run R&D facilities, in which case extensive and formal interactive learning may occur. Internal trade within the *chaebol* also gives individual firms a captive market and increases the feedback of information regarding the supplier firm's product and the supply of knowledge on technology and product changes. Such close contact means that suppliers can be especially responsive to changes in user demand, and, consequently, changes in product and production techniques can be implemented more rapidly.

(ii) Existing Skills and Technical Knowledge

The skill profile of a firm is to a large extent dependent on the other two internal factors: the size of the firm and the other products it manufactures. The skill profile (or the number and nature of capabilities a firm possesses) influences the firm's new product developments and its acquisition of new capabilities. Rosenberg (1976: 156-57) points out that there are common skills, techniques and know-how used in the manufacture of all mechanical engineering products. Thus, as already noted, experience in the operation of machine tools and metal working manufacture gives the firm a basic set of skills on which to base its entry into machine tool manufacture. Because of this transfer of

skills from one product area to another, the Korean firms described in Chapter 6 were specifically asked what products they had manufactured before they commenced machine tool production. Even skills which are not industry- or discipline-specific, e.g., in organisation and management, marketing, purchasing, and production planning, are important elements in the expansion of production or entry into new product areas.

Arguably, a firm's existing technical knowledge should be understood as including personnel's knowledge of the market and their personal contacts in that market. This sort of knowledge is unquantifiable, yet it can be a valuable source of market and product information for the firm. Experience from previous employment, friends in other plants/factories, contacts in government, research institutes and industry associations are all important sources of information and knowledge for the firm. Von Hippel's important study (1987) of steel minimills, has shown that networks of contacts evolve between engineers with similar interests who work for competing (and non-competing) firms. Through these links firms receive help in the solution of product and production problems. In the expansion of exports, information on foreign competitors, access to foreign agents, and links to an aftersales service network are all crucial. Similarly, if firms want to enter formal foreign technology agreements, contact with foreign competitors must be established. One way firms are able to build up contacts with foreign firms is by attending or exhibiting at the relevant international trade fairs. Chapter 6 shows that several Korean producers which had entered formal foreign technology agreements maintained close contact with their foreign licensors, even after the formal agreements had been terminated. These contacts had been used to obtain technical information and help in the solution of design and production problems.

Firms' investment in skill and capability creation is to some extent dependent on the national industrial environment. It has been suggested that employment practices are importantly related to decisions on investment in training. Thus, large Japanese firms with a tradition of life-time employment tend to invest heavily in training their personnel, there being little likelihood that they will leave to work for a

competitor (Peck and Goto, 1981: 241-42). Conversely, where there is a rapid turnover of employees firms are unlikely to invest in training. In such firms there may be no, or only a slow rate of, skill formation.

(iii) Compatibility with Other Products

A firm's existing products not only affect its skill profile but also influence financial aspects of entering new product areas. For example, if there already is plant and machinery within the firm which may be utilised in new product areas, entry costs will be lowered. Similarly, if operations or activities which need high volume or high utility to make the whole process economic can be shared with another product or production process, then the overall economic scale of production may be reduced. Such features influence the strategy of firms considering a new product area. Teece, for example, discusses the concept of "economies of scope". He contends that such an economy exists when "for all outputs y_1 and y_2 the cost of joint production is less than the cost of producing each output separately" (1980: 224). The direct application of this formula to the backward integration into machine tool production is problematic as there are few shared processes and cost advantages may only accrue to one product. For example, two Korean vehicle producers have found that by producing y_1 (production equipment) they can enhance the production processes by which y_2 (vehicles) is manufactured. This gives the main product (y_2) higher quality and/or lower costs without necessarily reducing the cost of production equipment (y_1).

Within conglomerates the compatibility of products is also an important issue. If firms within a conglomerate manufacture compatible products, they are able to take advantage of the close technological and trading links discussed earlier. Moreover, if there is a considerable overlap of their technology and their training requirements, they are able to establish centralised R&D and training facilities, which would be difficult for individual firms to finance.

2.4.2 External Factors

Utterback and Abernathy (1975) suggest that a firm's innovation attempts and production strategy will vary with its environment. Similarly, a firm's environment will influence its technological development. However, unlike the internal factors discussed above, individual firms will only be able marginally to change the environment in which they operate. Firms must, therefore, adjust their strategy to fit in with the prevailing environment. Three external factors are considered here: product technology, government policy, and industrial structure.

(1) Product Technology

In theory, technology could be considered as an internal factor, as it is in itself a product of the firm. However, as noted earlier, few industrialising country firms are at, or even close to, leading edge technology. These firms, therefore, are still principally importing technology and adapting it to their own specific needs and capabilities. And, as a result, technology is for them an external factor.

In analysing the acquisition of capabilities, the specific technology of the product must be considered. It is the technology which dictates the types and levels of capabilities required to operate efficiently in the relevant product sector. These capabilities can be importantly affected by changes in the product and in its production process, and such changes can either raise or lower capabilities requirements. For example, Hobday (1986) shows that in telecommunication switching systems the replacement of electromechanical devices by fully digital systems has reduced the skill requirements of assembly operations. The need for electromechanical interfacing has thus been reduced to a minimum and the majority of components needed may be purchased off the shelf. But new requirements have been created in other areas, such as the mastering of the complex software in the system. This, of course, has implications for the levels of skills required to enter production, and the ease with which they may be acquired.

The age of the technology and the emphasis on current developments in the product sector will also influence the strategy of the firm. Utterback and Abernathy (1975) contend that there are three stages in a product's development. Initially, there is an emphasis on the performance of the product; then product variety becomes the main priority, followed by attempts to increase product standardisation and to reduce costs. These stages not only affect the firms' competitive strategies, but also influence the extent to which they are prepared to transfer the technology. Only in the later stages are firms willing to license production, and, as noted above, the cumulative knowledge about the technology built up within the licensor firm will also influence the success with which it is transferred.

(ii) Government Policy

A primary role for government is the construction and maintenance of an infrastructure which can adequately support industrial development. Infrastructure consists of those organisations and installations which are necessary for economic and social activities but are only passively or indirectly involved in its functioning.²⁴ Installations include the supply of electricity, water, transport, and communications systems. Educational systems are also a vital component of industrial infrastructure and government's role in providing these is vital. In some countries governments also establish research institutes and training facilities whose services are generally available to all firms. These facilities do not constitute essential inputs, but, as they aid and accelerate industrial development, they can be seen as performing a catalytic role.

Governments also directly intervene in industrial activities to promote or protect certain sectors. Indeed, the machine tool industry has been heavily influenced by such intervention. In some cases, government intervention into the industry is as a purchaser of machinery to support its own defence interests. But in Japan the main thrust of government policy was to promote the machine tool industry so that the technological development of other sectors of industry would benefit.

Whatever aim government has in view, promotion of the machine tool industry can proceed by two distinct policies, protecting the domestic market or subsidising domestic production, which may be implemented individually or simultaneously. (The specific forms in which such policies have been implemented in different countries are treated in Chapters 4, 5 and 7.) Analysts have debated which type of government measure is of greatest benefit to the machinery industry and to machinery users. Datta Mitra (1979) argues that the imposition of tariffs is preferable to quantitative import restrictions, considering that the latter severely limit the choice of machinery on the domestic market, reduce foreign competition, and create inefficiencies. Tariffs, by contrast, give domestic producers an opportunity to exploit the domestic market, but allow machines to be imported if domestic products are inappropriate or unsatisfactory. The utilisation of schemes to subsidise domestic production for a limited time is also recommended, and this is the policy measure most favoured by Jacobsson (1986: 220). As the machine tool industry is internationally highly concentrated, and as there is a large gap between NIC producers and industrialised country manufacturers, this subsidy should, in Jacobsson's view, be limited to only a few makers who would then have the opportunity to catch up. Thus, while market protection gives all firms the opportunity to expand, the direct subsidy of domestic production enforces choice as to which firms are subsidised.

In the Korean case, both measures have been employed. The domestic market was protected, giving producers an assured market. But the measures introduced also ensured that machine tool users were not disadvantaged by these restrictions. Imports of sophisticated machinery which was not produced domestically and machinery which was manufactured domestically but of inferior quality continued to be permitted. Certain firms were also given considerable subsidies to enter or expand machine tool production. The firms chosen to receive this support were either *chaebol* members or the larger, and more technically advanced, independent firms; and, in the main, the technological development of these firms was far more successful than that of those which did not receive such subsidies.



Governments also subsidise the acquisition of technological capabilities. The establishment and funding of research institutes can be seen as direct subsidy of firms' product developments. A similar subsidy occurs when various tax incentives are given to firms to encourage investment in R&D and training. Additionally, governments can control the formal import of technology by domestic firms. These measures, which often include limits to the amount of royalty payable and the time span of the agreement, are usually implemented to try to ensure that technology and capabilities are effectively transferred.

The types of measures introduced by government are a major factor influencing firms' orientation towards import substitution or export. The overall protection of the domestic market and the strict regulation of imports encourages firms to be inward looking and to manufacture goods only for domestic consumption. Alternatively, firms can be given many incentives to concentrate on manufacturing for export. In Korea, exporting firms were given many subsidies compared to firms manufacturing goods solely for the domestic market. Through this form of influence, governments have fostered different types of technological development within domestic industries.

The Indian government, for example, introduced very strict protection measures with the aim of encouraging industrial self-reliance. Imports of all types were affected and indigenous production in nearly all industrial sectors, including those in which India had no comparative advantage, were consequently promoted. All industrial development and expansion was heavily regulated by government bureaucracy. The government also invested very large sums in scientific and technical research institutes. While there has been a considerable build up of technological capabilities in many sectors of Indian industry, there is little doubt that there still remain enormous technology gaps and that capabilities are often used very inefficiently. As Lall (1987) observes, a large amount of technological effort has been expended in coping with the high levels of import substitution required by the government. Moreover, the exclusion of imports also impeded the need to upgrade product technologies, since products developed elsewhere and containing new

technologies were not imported. Although, of course, there were many other factors which influenced the development process in India, Lall concluded that

[I]t does appear ... that an overwhelming portion of the blame for the failures of technological effort in India was economic: and can be traced directly or indirectly to economic policies pursued by the government (1987: 228).

In contrast, government intervention in Taiwan has been mainly in the promotion of exporting industries. However, the domestic market was also often protected for indigenous producers. Because of the requirement to export, these industries were forced to keep up with new technological developments and to manufacture competitively. As a result, the range of capabilities indigenised by export-orientated industries is concentrated in production and few capabilities in product design or development have been acquired. Thus, this strategy appears to have encouraged the acquisition of only certain types of capabilities. (The effects of this orientation on Taiwan's machine tool industry are discussed in Chapter 7.)

Teubal (1984) analyses the direct effects of Brazilian government policy on technological learning and exports of capital goods. He considers that an increase in Brazil's capital goods exports in the 1970s was not caused by changes in government policy at this time but occurred because of firms' increased technological capabilities. Firms had initially supplied the domestic market and their subsequent exports benefitted considerably from this experience. Consequently, Teubal recommends that prior to the acquisition of technological capabilities firms should be supported as infant industries and their main production should be for import substitution. He argues that direct export subsidisation of these goods at this time would have very high associated costs and a high chance of failure. Once firms had achieved an adequate quality in their production and had acquired a range of technological capabilities, then their exports could be promoted.

(iii) The Market: Buyers, Suppliers and Competitors

When trying to understand the development of an industry, it is important to consider the industrial structure in which it exists and the other industries which it influences and by which it is influenced, i.e., buyers, suppliers and competitors. Thus, Rosenberg notes that,

In examining the sources of productivity improvement in both industry and agriculture, we must pay attention to the fact that the performance of individual industries will frequently depend not only on resources available within the industry but on the availability and the effectiveness of industries which stand in an important complementary relationship with it. The technological inputs (including knowledge) which crucially affect the success of industry A are produced by industries B, C and D. Much of the discussion of the prospects and possibilities for technical improvement in poor countries has suffered from ignoring such interindustry relationships. We have to take account of these relationships and learn how to exploit them (1976: 169).

Similarly, Teitel (1984: 55) suggests that an understanding of the inter-industry flows of technical information and skills will help in the analysis of technical development.

The requirements of the domestic market are major influences on any product development. In the case of the machine tool industry, this market dictates the type of machine, the size, quality and price of products that will be sold easily. These factors influence the product strategy of the firm and, hence, the type of technology that has to be acquired and, indirectly, the method by which it is acquired. The international market exerts similar influences on export-orientated firms, but, because of the distance between maker and user, these linkages are much weaker and the feedback of information much more sparse. It should also be noted that many machine tool producers have their own internal market. With the exception of very specialised machinery manufacturers, firms use some of their own machines in their own production plants, and they are, consequently, both users and producers. This internalises feedback on machines, and can be an important element in product

development. This has been the case with the development of FMSs by some larger machine tool producers.

The importance of the machine tool industry to the domestic manufacturing sector has been widely acknowledged, but the nature of their relationship has scarcely begun to be explained.²⁵ For the machine tool industry, the structure of its market is extremely important, as it influences product strategy and the types of skills which need to be acquired. And vice-versa, only if the machine tool industry successfully acquires these skills can it supply its markets with the machines required. This consideration is far more important with respect to the industry's domestic users than to its foreign markets. On the domestic market, the machine tool industry is very important in the supply of skills relevant to the choice and installation of new machinery, repair and maintenance of existing machinery, customisation and special purpose design. Chapter 4 describes the precise way in which certain domestic industries have shaped the character of their main machine tool suppliers, and Chapter 6 considers the importance of certain sectors of the Korean domestic market and their influence on the development of the industry.

The role of users in product innovations has been discussed by several analysts. For example, Von Hippel's study of innovation in the manufacture of scientific instruments (1976) showed that about 80% of innovations in that industry were, in fact, invented, tested or manufactured as prototypes by users themselves. However, this relationship in industrialising countries is not only a mechanism by which new innovations are transferred, but it also appears to be an important aspect of the learning process. Makers and users work closely together, in order to upgrade their respective technologies, increase their knowledge, and improve quality.

There is a similar relationship between the machine tool industry, as a user, and its component suppliers. Innovations, knowledge and skills transferred through these links are limited to the technology of the individual part or component being supplied. The machine tool industry has always utilised and responded to product developments by its supplier

industries, in order to improve its own products. For example, in response to the introduction of high-speed steel cutting tips by tool makers, machine tool producers designed machines with much greater rigidity, able to withstand the increased stress during operation at far higher cutting speeds. Because the manufacture of CNC machinery is far less vertically integrated than that of conventional machinery, machine tool producers have become more dependent on component suppliers. In particular, many machine tool producers (and in the industrialising countries nearly all) rely on specialist controls producers. The technological dynamism of these component firms therefore influences the technological progress of the machine tool industry as a whole. Moreover, there appears to be considerable variation between different countries as to the closeness of this relationship and the subsequent development of national industries.

Competition within an industry is an important factor both in technological development and innovation. The introduction of a successful new product, or a low-priced item, by one manufacturer forces other firms in that sector to evaluate such changes and make adjustments to their own production.²⁶ The absence of such competition can, as demonstrated by the Indian case, lead to technological stagnation. Inevitably, competitors are also an important source of technical knowledge and suppliers of technology to other firms.

Potential competitors are the main source of new technology when it is acquired through a licensing agreement, and in these cases there is often considerable technical support given to the licensee. The licensor is directly selling its technology, and, in order to try to minimise direct competition from the licensee, regulations on the sales of the item are included in the agreement. There are also less formal ways in which firms help competitors with technological problems and in which there is no direct payment. This occurs both between firms which are direct competitors and those which are not (see Von Hippel (1987, 1988) and Allen et al. (1983)). Such transfer of knowledge and technology principally occurs through the personal contacts established by employees at competing firms who consult each other on specific problems.

However, when a product is bought by a producer and then copied, the original manufacturer has no involvement in the transfer. In these cases the firm which developed the product is only unintentionally the source of a competitor's new technology.

This chapter has shown that the major benefits of an indigenous machine tool industry flow from the pool of technological capabilities built up by that industry and its consequent ability to support the whole manufacturing sector. Yet the nature of those capabilities is strongly influenced by the type of technology incorporated in machine tools. Technologies and capabilities evolve together. A given mechanical technology requires a certain set of capabilities to construct, operate and maintain it. And that pool of capabilities then forms a base for further product development both in the machine-making sector and elsewhere in the machine-using sector. What is required, therefore, is a detailed account of CNC technologies and the capabilities they demand.

Notes

1. See Little (1982) for a comprehensive review of many of the approaches taken.
2. Many of these studies were part of a research project on "The Acquisition of Technological Capability" financed by the World Bank. More general reviews and edited books containing similar material include: Stewart and James (1982), Fransman and King (1984), and Fransman (1985).
3. For comprehensive accounts of the historical role of the machine tool industry in technical development, see Rosenberg (1976: Ch. 1) and Fransman (1986a: Ch. 1).
4. Such a crisis is to some extent demonstrated by the case of Mexico. Singh suggests that the huge increase of imports into Mexico between 1977 and 1981 led to a national crisis because of the disequilibrium of the balance of payments. A very high proportion of these imports (90%) were capital and intermediate goods. Singh says that "the development and growth of the indigenous capital goods industry must play a central role" in the restructuring of Mexico's productive system (1986: 264).
5. While this was the case when Datta Mitra wrote in 1979, Chapters 4 and 7 show that this is no longer so, as the US has protected its markets against Taiwanese machine tool exports and warned Korea against increasing its exports.
6. This type of linkage is important between many other complementary industries, as well as between machine tool producers and users. In fact, Lall suggests that it may be the most important of all the linkage types he examined in his empirical study (1980).
7. In the NICs, these skills are often initially formed in small work-shops and repair shops, as well as in manufacturing industry.
8. "Infant industries" are those industries which are being established for the first time in an economy, and which, without special treatment, would either not be started up or develop sufficiently. For a detailed analysis of the case for government promotion of the capital goods industry, see Datta Mitra (1979).
9. There are, of course, many questions about the appropriate allocation of resources between the machinery sector and the machine-using (manufacturing sector). The so-called Feldman-Mahalanobis model designed to show the consequences of various strategies was initially developed in the Soviet Union in the 1920s and was extended in the 1950s for the Indian case. This model shows how different allocations of machinery output into either the machinery sector itself, in order to manufacture more machines, or into the machine-using sector for the production of consumer goods, affect the build up of machinery in the economy. The model has been further extended by Harris, to include foreign trade, and by

Cooper, to incorporate the effects of learning by doing. For a full description of this model, see Cooper (1984) and Fransman (1986a: 4-8).

10. In Japan and Korea, the machine tool industry was promoted as a part of a more extensive plan to develop heavy industries, so that the machine tool industry could support domestic industries at an early stage.
11. For example, in the Basic Development Plan for the Machine Tool Manufacturers introduced by the government of Korea in 1977, different sectors of the industry were promoted for different reasons, and some were specifically excluded: basic conventional machines were promoted for export; some more complex machines were encouraged for import substitution; high-precision and highly automated machine tools were not promoted at all (for details, see Bendix et al., 1978: 44).
12. For example, the Indian government regulated the import of nearly all types of machine tools, while in Korea and Japan governments were very careful to continue to allow the importation of high-cost, sophisticated machines, and protected only the sector of the market in which domestic industry could fairly quickly reach international standards.
13. Lall (1987: 4-11) also uses these five categories of technological capabilities and describes them in great detail.
14. Kim Young-Woo (1981) compares technical development in two vehicle producers in Korea, one a joint venture and the other almost entirely Korean owned. In the joint venture, the foreign parent company ran extensive training schemes in assembly, maintenance and quality control. These schemes were available to a greater proportion of the employees and were more detailed than those run by the Korean-owned firm. However, there was no attempt to transfer capabilities in product design from the parent company to the joint venture.
15. Park Woo Hee (1983: 80-81) describes how the agreement for the installation of a petrochemical plant in Korea by Dow Chemical included the training by Dow of Korean engineers in many technical areas, including the construction, testing and start-up of the plant. The capabilities gained through this venture were utilised in the later construction of a second plant.
16. See Chudnovsky (1986: 75-77) for an analysis of these costs.
17. See Chudnovsky (1986: 73-78) for a more detailed discussion of the disadvantages of formal technology transfer agreements.
18. See Fransman (1984b: 312) for a brief survey of other studies pointing to this type of information flow as a source of technological capability.

19. Fransman compared several specifications of his sample Taiwanese firms' machines to those manufactured by their direct competitors, thus comparing like with like. From this comparison, he was able to derive an indication of the gap between his sample and the "best-practice technology frontier" (1986c: 1391). While this analysis was valuable in showing the overall performance of the firms in comparison to the international market, it gives little indication of the actual capabilities acquired and, consequently, reveals little about the firms themselves.
20. There are also a number of intrinsic difficulties in using the variables Jacobsson (1986: 105-08) suggests to measure design capabilities. The establishment of a marketing network is, for example, more an indication of the scale of production and exports than of the technical capabilities of the firm. In many of these cases, a marketing service was established for the sales of conventional machines, and, as such, gives no indication of capabilities in the production of CNC machines.
21. The sophistication of products manufactured and the level of indigenous capabilities can be represented on a matrix. See Nolan (1986: 46) for an illustration of a matrix constructed to show the sophistication of defence production and the level of production capabilities acquired.
22. Similarly, Enos's game theoretic approach (1982) to the choice of technology views only the process of decision making as continuous, and considers that to focus on a particular time or event misses influences that have occurred before and elsewhere as well as neglecting subsequent developments. Furthermore, he argues that to focus on one individual misses the contribution of others, and to focus on a new technology misses alterations that occur through adaptations and improvements.
23. For a more detailed account of the relationship between size of firm and the rate of innovation, see Freeman (1974: Ch. 6) and Rothwell and Zegveld (1982). See Schon (1982) for a discussion of why large corporations may resist the introduction of new innovations.
24. An adequate definition of infrastructure is offered by Müller: "a general denominator for all projects and services which the state establishes, controls or maintains for the purpose of its actual production development policy ... and which in principle can be collectively utilized or consumed" (1980: 31).
25. As already noted, Jacobsson (1986) recognised that there were potential benefits from the capabilities built up in an indigenous machine tool industry through its technological input to other industrial sectors and its role in the diffusion of new technologies. However, while examining the potential size of the domestic market in Taiwan, Argentina and Korea, he did not cover the specific requirements of the users in these markets, or the nature of links between producers and users. Fransman, while recognising the importance of maker-producer links, and noting the importance of

users as a source of improvements, does not explore in detail why these links are so different for the two countries he considers or how these links have influenced technological development in the machine tool industries (1986a). A notable exception is Watanabe (1983) who did relate market structure and technological development in the Japanese machine tool industry. He suggested that Japan's vehicle industry had played an important role in the development of the machine tool industry. (This case is covered Chapter 7.)

26. Schumpeter suggested that such actions compelled other competitors to introduce changes (Fransman, 1986a: 18-19).

CHAPTER THREE

Machine Tool Technology and Capabilities

If an industrialising country is to establish a CNC machine tool industry a range of technological capabilities must be acquired. Not all of these capabilities can be secured with equal facility and, indeed, some capabilities may, in practice, prove impossible for certain countries or companies to acquire. Thus, the acquisition of technological capabilities constitutes a set of requirements and a set of potential barriers to entry. This chapter argues that one cannot properly appreciate the process of technological development, in general, or the build up of technological capabilities, in particular, without confronting the detailed skill requirements of the relevant technologies.

How do the technologies embedded in CNC machine tools differ from those of conventional machines? How does control unit technology differ from the technologies of the CNC machines whose cutting they control? Conventional machine tool capabilities are largely mechanical. Such capabilities have proved relatively easy to acquire for NIC producers, as a pool of relevant skills typically develops within a machine-using economy. By contrast, CNC design and production make special capability demands; their configuration is more complex, their assembly is difficult, and their design requires specially skilled personnel. An adequate pool of appropriate capabilities does not usually pre-exist in a NIC and deliberate steps have to be taken by firms to acquire them. Finally, control unit technology exerts the most exacting capability demands. And neither of the NIC CNC machine tool industries surveyed in this study have, as yet, successfully acquired relevant capabilities in this technology.

3.1 Machine Tools and Their Operation

Metal cutting machine tools can be classified by the two main ways they cut the workpiece: those in which the workpiece is rotated and those in which the tool is rotated.¹ The principal type of machine in which the workpiece is rotated is the lathe, and it is used to cut cylindrical parts.

(Figure 3.1 shows an engine lathe.) The major parts are the bed, the chuck, the head and tail stocks, and the carriage. One end of the workpiece is fixed into the chuck, which is mounted on the main spindle of the machine; the other end is mounted on the tail stock. The tail stock may be clamped at various positions on the bed to accommodate different lengths of workpiece. If the workpiece is short, it only needs to be gripped by the chuck. The workpiece is rotated in this position, the power being supplied through the main spindle. A single point tool is clamped into a tool post on the carriage, and may be moved in two directions in relation to the workpiece - longitudinally and radially, i.e., on the Z and X axes. The cutting edge of the tool is pushed onto the rotating part to cut the metal. If the cylindrical part is large, and therefore heavy, it is impractical to mount it horizontally, so a vertical boring machine is used, on which the workpiece is mounted on a horizontal rotating table.

The simplest machine using a rotating tool is the drill press, in which a twist drill is rotated and may be fed along its axis of rotation. For larger pieces of work a radial arm drill is used. On this type of machine, the head is supported by an arm which may be rotated, raised and lowered on a column so that large areas of workpiece can be covered. The most important type of machine in this second category is the milling machine. These machines may have their spindles mounted horizontally or vertically, and are consequently called either horizontal or vertical milling machines, an example of which is shown in Figure 3.2. To operate these machines, a multi-faced tool is attached to the spindle in the head of the machine, and the workpiece is clamped to the table. The table may be moved in three axes, X, Y and Z, but usually only the X and Y axes can be co-ordinated in order to shape profiles, while the Z axis is set for each cut. On larger milling machines, the saddle is mounted directly on the bed of the machine, and motion in the Z axis is achieved by moving the head up and down on the column. When the depth of cut is set for each cutting operation, and is not altered while the table is moved in the X and Y directions, this is known as 2½-dimension control. Only when the depth of cut can be varied, to produce contours, does the machine have

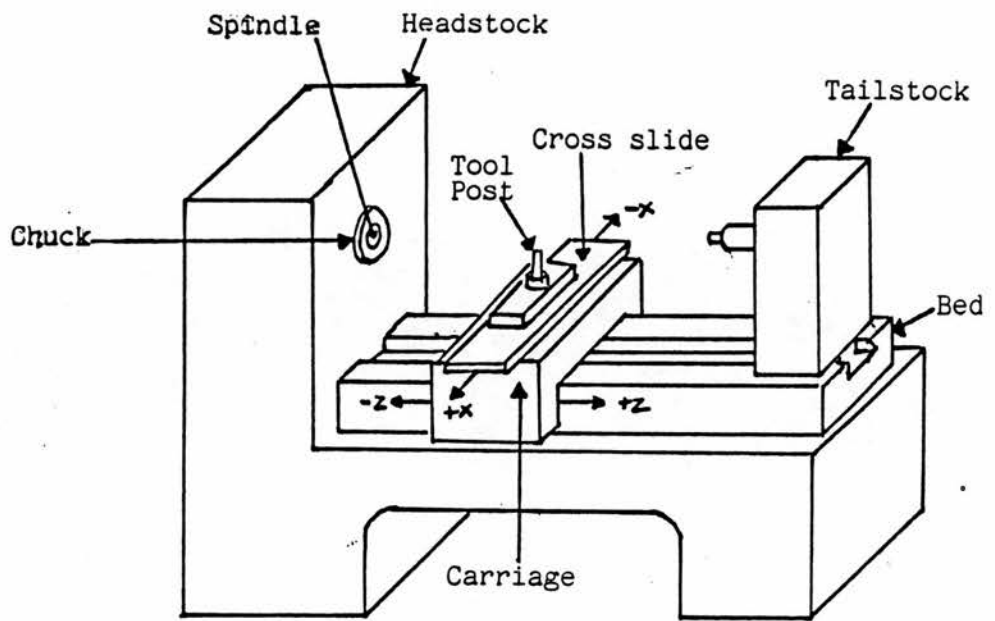


Figure 3.1 Main Parts of an Engine Lathe

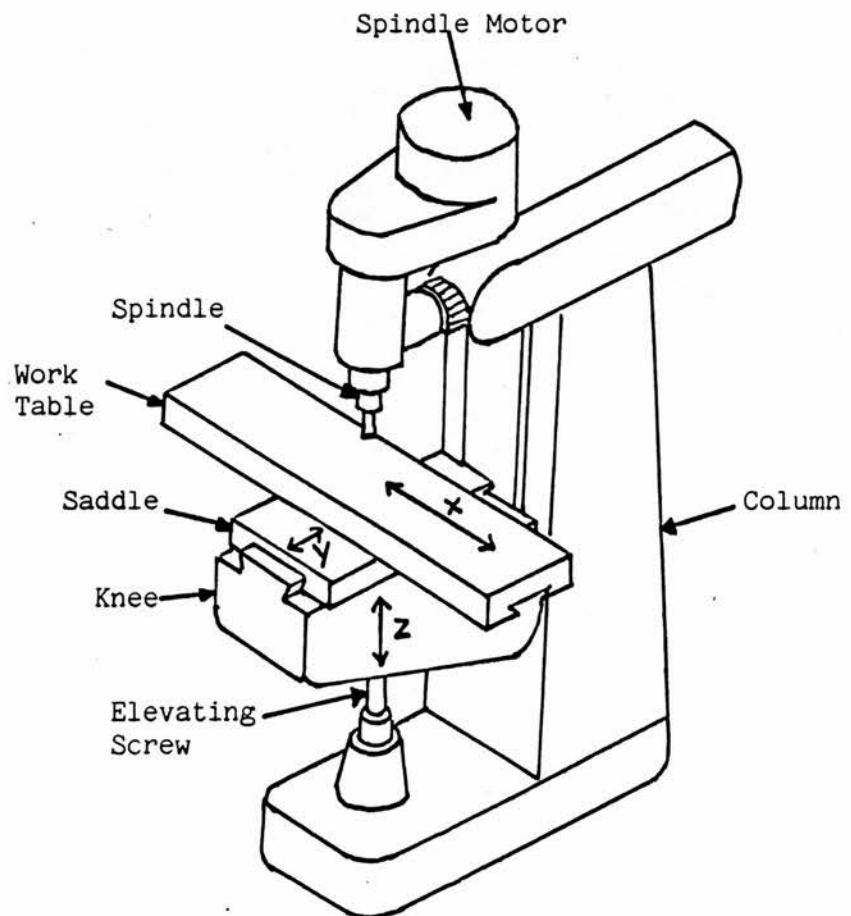


Figure 3.2 Main Parts of a Vertical Milling Machine

full 3-dimensional control, i.e., the Z axis can be fully co-ordinated with the X and Y axes.

Two other types of metal cutting machines are planers and grinders. On planers, a single-edged tool is held at a constant height while the workpiece is moved reciprocally beneath it and the cutting tool is fed at right angles to this motion. Planers are used to generate flat surfaces on very large parts. Grinders have an abrasive wheel which is attached to a spindle and rotated at high speed. Grinding machines may be built on similar lines to either lathes, milling machines or planers, and so can cut either flat surfaces or cylindrical parts.²

These types of machine tools were principally developed in the latter part of the eighteenth and the early nineteenth centuries. They were initially invented to cut pistons accurately and to bore holes in cylinder castings used in the first efficient steam engines (Gilbert, 1965: 421).³ The horizontal boring machine developed by John Wilkinson in the 1770s was used to produce parts for steam engines and to bore cannon. The lathe was extensively developed and improved by Henry Maudslay in the 1790s. Maudslay applied to general metal working standards of precision which had previously been used only in the manufacture of small items such as scientific instruments (Rolt, 1965: 86). He also adopted an all-metal construction for his machines. The milling machine, although in use in the early nineteenth century, was improved upon after 1850, and the first universal milling machine was delivered in 1862 (Floud, 1976: 29).

An early development which increased the productivity of lathes on medium-batch production was the introduction of the turret or capstan lathe in the 1850s (Floud, 1976: 26-27). On these lathes, the tail stock is replaced by a tool holder in which a number of tools are clamped in different pre-set positions. The tool holder can be quickly rotated so that a sequence of cutting operations may be undertaken without having to re-fit the tool for each separate cut. The first automatically controlled lathe was introduced in the US in 1873 by C.M. Spencer, using what he termed a "brain wheel" - in effect a cam.⁴ Two separate brain

wheels controlled the cutting tool and the turret (Rolt, 1965: 169). The use of cams was extensively developed to control screw-cutting and other special purpose machines. A further development was the semi-automatic lathe, on which bar stock is automatically fed through the chuck and the different tools are brought into position using a camshaft.

The "American system" of interchangeable manufacture - the manufacture of standardised parts to fit an established production model rather than the customised production of each part - was first introduced by Eli Whitney in 1798 to manufacture muskets. However, it was not until the early 1850s that these principles were applied to all stages of production at the Colt Armory in Hartford, Connecticut. And in 1853 the "American system" was introduced into Britain's workshops (Galloway, 1965). Interchangeable manufacture promoted the development of jigs and fixtures. Jigs guide the machinist in locating and directing the cutting tool, while fixtures hold the workpiece in position on the work table. Both jigs and fixtures are specifically designed for use with a particular workpiece and are therefore mainly used in batch production, when the size of batch merits their manufacture. The introduction of jigs and fixtures and capstan and semi-automatic lathes enabled machines to be set up by skilled machinists and then operated by semi-skilled workers. Although their set-up time was longer and their tooling costs greater than on basic machines, the actual cutting time for each piece was considerably reduced and repeatability was improved.

3.1.1 Special Purpose and Custom Designed Machine Tools

The machines described above have been considerably developed into the late twentieth century and form the core of general metal working machines used at present. But for particular machining jobs - such as large-scale or mass production, very high precision work, very large or very complex workpieces - standard machines may be substantially modified or a special machine designed: these types of machines are known as "custom designed" and "special purpose" machines. In the case of large-scale production, special purpose machines are designed to automatically

manufacture one part or at most a few simple variations of a single part. Because these machines are set up to manufacture only this type of part, they are able to work at a much greater rate. Consequently, the higher cost of the machine is compensated for by a reduction in workpiece cost.

High precision machines are commonly used in defence production, aerospace manufacturing (rockets and satellites), and the machining of turbine blades. Some of these parts need to be machined to the sub-micron level. Small precision machines are also manufactured to cut very small workpieces, including watch and clock parts. The structure of precision machines has to be very rigid to eliminate distortions during the cutting process. This requirement means that higher quality materials must be used and the precision to which the parts of the machine itself is made needs to be greater than for standard machines. In addition, extra instrumentation is often added to the machine to check the dimensions of the workpiece as it is being cut. Because of the very high quality of these machines, they are extremely expensive.

Most machine tools are designed to cut relatively small parts. Lathes have beds approximately a metre and a half long (although some heavy duty lathes have beds up to four metres long), and can turn workpieces with a maximum diameter between a quarter and a half a metre. Milling machine work tables have areas of less than a square metre and the tool can move vertically by less than half a metre. These machines can also only take workpieces up to certain weights. Machine tools may be customised in order to accommodate work pieces of larger sizes, or special machines may be designed. The machine tool industry itself uses very large planing and grinding machines to machine the surfaces and slides of cast-iron beds. Very large lathes are used to turn wheels for rolling stock and large-scale milling machines are used for cutting some aircraft parts. Other machines are designed to cut shapes that cannot be, or are not easily, cut by standard machines. This includes the cutting of gear wheels, cams, crankshafts and some types of threads.

There is no strict division between standard, custom designed, and special purpose machines. Standard machine tools contain a very high

proportion of standardised components - generally more than 80 percent (Sciberras and Payne, 1985: 22). Customised machine tools are built from standardised components and a significant proportion of non-standard components; the latter are custom designed so that the machine meets the specific requirements of a particular user. Special purpose machines may be entirely made of custom designed parts or, if they are manufactured in any number, may contain a high proportion of standardised parts.

There is an additional group of metal cutting machine tools of recent origin which use non-traditional methods of removing metal. The most widely used type in this group is the electro-discharge machine (EDM). These machines only work on metals that are good electrical conductors. The workpiece and the shaped tool are charged so that one is a cathode and the other an anode. Both electrodes are placed in an electrolyte, so that there is a spark discharge in the small gap (less than a millimetre) between the tool and the workpiece. The sparks remove small quantities of metal and, hence, shape the workpiece. On some machines a thin wire is used for the cutting electrode instead of using a shaped cutting tool. EDMs are mainly used for cutting tools and dies in the plastics industry. Lasers are also increasingly being used to cut metal and other materials, as well as being attached to other cutting machines as measuring devices. Lasers can cut and engrave very hard materials fairly easily; they can be used to cut very intricate shapes and small holes, and to cut thin metal sheets and wood in general production areas. In addition, laser cutters and markers are used in the electronics industry. Other devices in this category include machines cutting with ultrasound, abrasive and water jets, electrochemical reactions, and ion beams.⁵ Together, these machines only form a very small part of the metal working machine tool industry. Their use is, however, increasing as they can be used to machine very hard and brittle materials, as well as to cut complex shapes.

3.2 Development of Machine Control

The introduction of automatic and semi-automatic lathes enabled the production of some mass-produced components to be automated. But the design and manufacture of cams is a long and complex process. And, although cams can be changed in order to manufacture different parts, this is not an easy task. Therefore, automatic and semi-automatic lathes have to manufacture long runs of a single item to be economic. Different methods of control which could be more flexible in their application were experimented with from the eighteenth century. The control of machinery by punched cards goes back to the development in the 1720s of the Jacquard Loom, which produced knitted patterns. Tracer technology was applied to woodcutting lathes by Thomas Blanchard in 1818, in Worcester, Massachusetts, in order to reproduce gun stocks. On Blanchard's machines, a stylus followed a template. The stylus was linked directly to the tool cutting the workpiece, so that all the power required to move the tool came from the operation of the stylus. However, this type of control could not be applied to metal cutting machines because of the greater leverage required (Rolt, 1965: 241).⁶

Early applications of tape control to metal working machine tools occurred in the US in the first decade of the twentieth century. However, it was tracer technology that was first developed to any extent. The Keller electro-mechanical duplication system for metal working was invented by John Shaw in 1921. On this machine, the stylus was used solely for information, and power from an electric motor guided the cutting tool. In the 1930s and 1940s, tracer technology was further developed, using a combination of electrical, mechanical, hydraulic, and pneumatic mechanisms. The most popular system was a hydraulic one developed by Cincinnati Milling Machine Co. and used on their "hydrotel" tracing machine. By 1942, General Electric had developed an all-electronic control system. This technology was superseded in 1946 by "record playback", also developed by General Electric. Record playback involved a skilled machinist making a part while the motions of machine and tool were recorded on magnetic tape. The tape was then played back through the machine, so repeating the operations and automatically

producing an identical part (American Machinist, Nov. 1977). (David Noble's admirable Forces of Production [1984] documents the American development of record control and numerical control in the 1940s and 1950s and much of this account is informed by his valuable work.)⁷

3.2.1 Development of Numerical Control

Numerical control (NC) is a system for controlling machine tools using digital information (prepared away from the machine) which details the shape of the part to be machined. The digital information is then fed into the machine to control its movement. This technology is different from either tracer technology or record playback as no prototype part has to be manufactured for the machine to copy automatically. The original development of NC for machine tools is generally considered to have been the work of John Parsons (incidentally a machine tool user and not a producer). During World War II, Parsons had been a US defence contractor producing army ordnance, and in the course of his work he developed ingenious methods to automate production. After the War, military demand was still high. Furthermore, this demand reflected the technological advances made during the War. Parsons wanted to diversify his business, so he turned to the production of rotor blades for helicopters, in the ultimately mistaken belief that the commercial helicopter business would expand rapidly in the early 1950s. For the production of the complex helicopter blade templates, he used an IBM 602A multiplier to calculate the aerofoil co-ordinates. He then used these data points on a Swiss jig-borer to cut the template. Previously, seventeen points along the curve were calculated, and the points were joined manually. This method was time consuming and subject to large inaccuracies. Using the new method, 200 points were calculated and accuracy was significantly improved. For example, the tolerance was reduced from $\pm 0.009"$ to $\pm 0.001"$. The use of the IBM multiplier eliminated the majority of the tedious bench work, but the jig-borer was positioned manually at each of the 200 co-ordinates for holes to be drilled. Parsons reasoned that if a punched card could direct a tabulating machine to a co-ordinate, it could also direct a machine tool,

i.e., the data he had from the multiplier could be fed directly into the machine tool. (Noble, 1984: chs. 5 - 6)*

The U.S. Air Force became interested in Parson's idea and its potential application to the production of parts for its new high-performance fighter. In June 1949, the Air Force contracted Parsons to design and build an automatic contour cutting machine which could be controlled by punched cards or tape, and which would be able to perform automatic contour cutting. Having obtained a contract to build a machine, Parsons then had to find collaborators to work on the parts of the machine that could not be designed and built by the Parsons Corp. itself. In the original plan, a machine manufactured by Snyder Tool and Engineering Co. was to be adapted and fitted with a control unit developed by the MIT Servomechanisms Lab. and a card reader developed by IBM. Parsons Corp. would assemble the whole machine, and would manufacture and market the new machines.

Having been included in the project, the Servomechanisms Lab. began to exert influence on the development of the new machine. Firstly, they changed the type of machine to be adapted from a Snyder special milling machine to a Cincinnati "Hydrotel"; secondly, they replaced the IBM card reader with MIT's tape reader; and, finally, they changed the specification of the machine to make the motion more sophisticated, by using full three-axis control, which Parsons had not envisaged in his original specification. By insisting on all these changes, MIT successfully managed to force Parsons out of the project and to develop the new machine themselves, with further financial support from the Air Force. In September 1952, a three-day public demonstration was arranged at MIT to show the newly developed machine. The machine was controlled by "the director", which consisted of six standard relay racks, constructed on flat panels, each relay rack containing approximately 125 relays and 270 electron tubes. Nearly 300 pilot lights continuously indicated the state of every important circuit and relay in the system (Servomechanisms Lab., 1953).

The system utilised servomechanisms in its control of the machine's movement. This was also a radical innovation in the control of machine tools as it involves feedback to enable the machine to correct itself.⁹ A servosystem has been defined as,

an automatic control system incorporating power amplification and feedback designed to make an output variable quantity follow an input variable quantity closely. The feedback system compares the output and input variables and produces an error signal, which depends on their difference, and which is then amplified and used to correct the output signal continuously (Martin 1983: 289).

MIT continued to develop NC with Air Force support. In 1952, MIT collaborated with Bendix Corp. on an NC application to make cams for aircraft fuel control devices; and, in 1953, they worked with Kearney and Trecker to make the first commercial NC machines. In addition to supporting the work at MIT, the Air Force took over financial responsibility for getting this technology into defence factories (Noble, 1984: 134). In 1955, the Air Materiel Command Budget allocation for the stockpiling of machine tools changed from tracer controlled to NC machines. The Air Force undertook to pay all the expenses of purchase, installation, maintenance, and training for 100 NC machine tools to be placed in factories of important sub-contractors. In total, the military spent at least \$62 million on the research, development and transfer of the technology between 1949 and 1959, when the Air Force withdrew its formal support for the development of software.

3.3 Advances in Control Unit Technology

Machine tool control units have developed in line with the rapid advancements in microelectronics. Advances in electronics have contributed to three areas of improvements in machine tool control. Firstly, there has been an increase in the complexity of the cutting path that the control unit can process and in the number of machine functions which can be simultaneously controlled; secondly, control units have become far more reliable, and, thirdly, the cost of the control unit has been reduced, meaning that more control can be bought for less. The types of control unit and the electronics technology used may be divided into seven generations, as shown in Table 3.1.

Table 3.1 Generations of NC/CNC Control Units

Generation of NC/CNC	Year Introduced	Main Electrical Elements
1st	1954	Vacuum tubes and relays (analogue circuits),
2nd	1959	Transistors (digital circuits),
3rd	1965	ICs (digital circuits),
4th	1970	Softwired, LSIs, built-in microprocessors,
5th	1974	Built-in one chip microprocessors,
6th	1979	VLSI, bubble memories, increased use of CRT,
7th	1981	Interactive methods, customised software for automated systems,

Source: Metalworking, July 1987; 19.

The first three generations were generally known as "hardwired" controls, since they consisted of discrete components connected by wires.

Later generations are known as "softwired" controls, because the outputs are wired directly to the electromechanical devices on the machine, and the switches and sensors are wired to inputs through an input/output bus without the use of relays. In 1974, control units were built incorporating a microprocessor. Because these units had a computing ability, they were distinguished from NC units and designated as Computer Numerical Control (CNC) units.¹⁰

The main components of an NC unit are shown in the block diagram in Figure 3.3. The punched paper tape is fed through the tape reader intermittently and read just one step ahead of the machining operation being performed. This information is stored in the buffer, so that the eventual input command to the machine is continuous. It is important that the instructions are continuous, so that the tool does not dwell during the cutting operation (except where explicitly required) while it waits for the next instruction. The signal from the buffer goes through the interpolator, which processes the information and issues commands in the form of electrical pulses to the axes and spindle motor simultaneously. Each axis is geared to a feedback mechanism, usually a rotary digital instrument.¹¹ The feedback pulse and the input from the interpolator are both fed into the error register, which compares the two signals and transmits the difference to the servo-amplifier. The servo-amplifier and the related circuitry convert the error signal into analogue form and amplify it. The signal then activates the drive mechanism on the machine axis (Sung, 1958: 436).

The first NC control units have been described as "huge, unreliable, masses of vacuum tubes and relays" (Merdinger, 1977: 695). They were also expensive, in comparison to the machine cost, and very complex. Those sold commercially utilised electromechanical relays rather than vacuum tubes (Groover and Zimmers, 1984: 204). As relays were susceptible to wear, these systems were inherently unreliable. The later replacement of relays by transistors avoided this wear problem and, thus, increased reliability. These components were also smaller and allowed for more complex circuitry. This meant that more sophisticated logic functions could be implemented - such as circular interpolation, tool

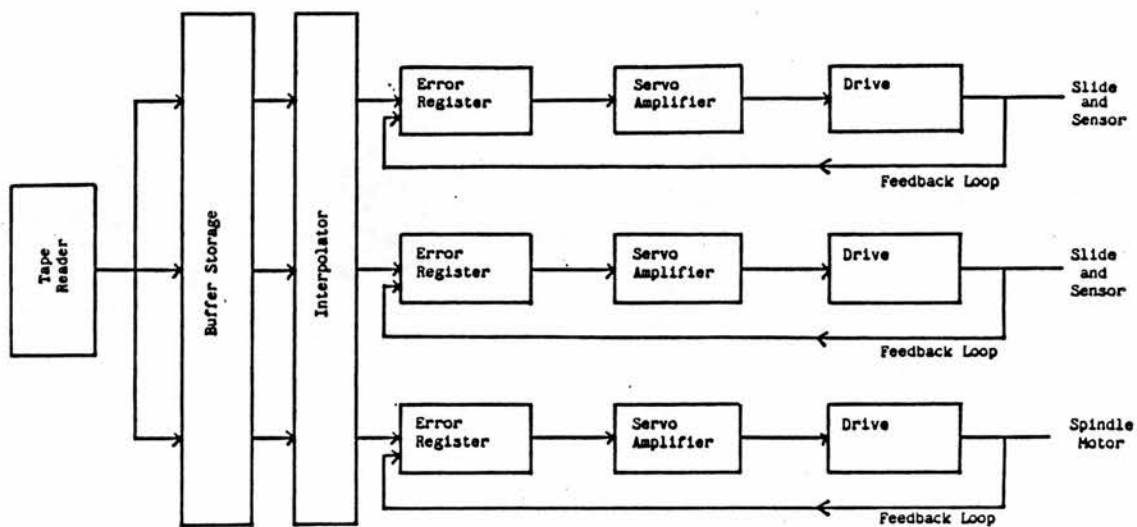


Figure 3.3 Block Diagram of an NC Unit

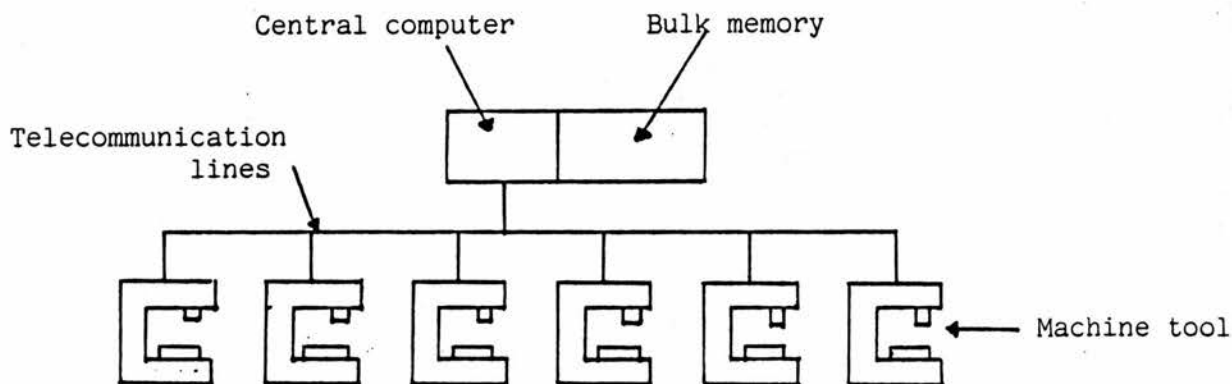


Figure 3.4 Schematic Diagram of Direct Numerical Control

offset, tool radius and cutter radius compensation, word address control, and spindle speed control. There were still reliability problems which were exacerbated by the heat sensitivity of the electronics: in some cases fans or air-conditioners had to be installed in the control cabinet to enable the controls to operate in the work-shop environment. The use of integrated circuits reduced the number of separate components in the system by 90%, as well as reducing the cost considerably (Groover and Zimmers, 1984: 205). In addition, more features were incorporated in the control unit; these included hyperbolic interpolation routines, duplicate functions (such as inch to metric conversions), absolute or incremental co-ordinate specification, and vector feedrate computations.

All the hardwired systems had a number of problems. Often mistakes were made in part-programming, and several runs of the tape had to be made to prove the tape before it could be used in production. The part-programmer also had to set feeds and speeds in the program for the worst case, to ensure that the program would function under all conditions.¹² As there was no opportunity for these variables to be changed later during the cutting process, the machine was usually run at sub-optimal speeds and feeds. The control units themselves were difficult to modify or update, because any programming of their operation had to be performed by re-wiring the components to the unit. A major problem was the use of paper tape and tape readers to transfer the program into the control unit. The punched tape was fragile, becoming worn and susceptible to tearing after repeated use. Additionally, the tape readers were frequently the most unreliable components in the control unit hardware, either through mechanical breakdown or misreading tapes (Groover and Zimmers, 1984: 204).

The use of a dedicated computer as part of the control unit was achieved as early as 1964. But because of the very high cost of computing power at the time, this method of control was not commercially viable. The only feasible approach was to use one big computer to control a number of machine tools on a time-shared basis. This system was developed in the late 1960s and is known as Direct Numerical Control (DNC). DNC consists of four basic components: (1) the central computer;

(ii) the bulk memory, which stores NC part programs for transmission to the different NC machines; (iii) the telecommunication lines; and (iv) the machine tools themselves. (The layout of these components is shown in Figure 3.4.) There is two-way information flow between the machines and the computer. The machines request instructions and send other information to the computer, which must respond with instructions so that the machine is not left idle. Instead of using punched tape for program storage and as the input medium, disc storage may be used.

In 1971, Intel introduced the microprocessor chip, on which there was a central processing unit (CPU) capable of operating as a computer. Its introduction reduced the cost of dedicated computing power, and so made it viable to add a programmable logic controller (PLC) to the numerical control unit. This addition changed NC to Computer Numerical Control (CNC). (The main components of a CNC control system are shown in the block diagram in Figure 3.5.) The core of the control unit contains both a numerical controller and a PLC, and these organise the control of the machine axes and other functions of the system as a whole. The NC component deals with the real time control of the machine axes and spindle motors, while the PLC controls such functions as tool management, and pallet changing, as well as undertaking computational functions for the NC part. There is also a memory to store the system software. Commands are relayed to an input/output system, which, through an interface, links the control to the machine itself, and to different outside peripherals.¹³

The major advantage of CNC is that the memory in the control unit can be changed by altering the program, rather than by re-wiring the whole system. Softwired controls also allow for standard control systems to be built for groups of similar machines, and then adapted by programming, to control specific machines. More functions were made possible, including programming aids and diagnostics. The systems also allowed for program editing on the machine, enabling programs to be proved on the machines and faults rectified or changes made instantly.

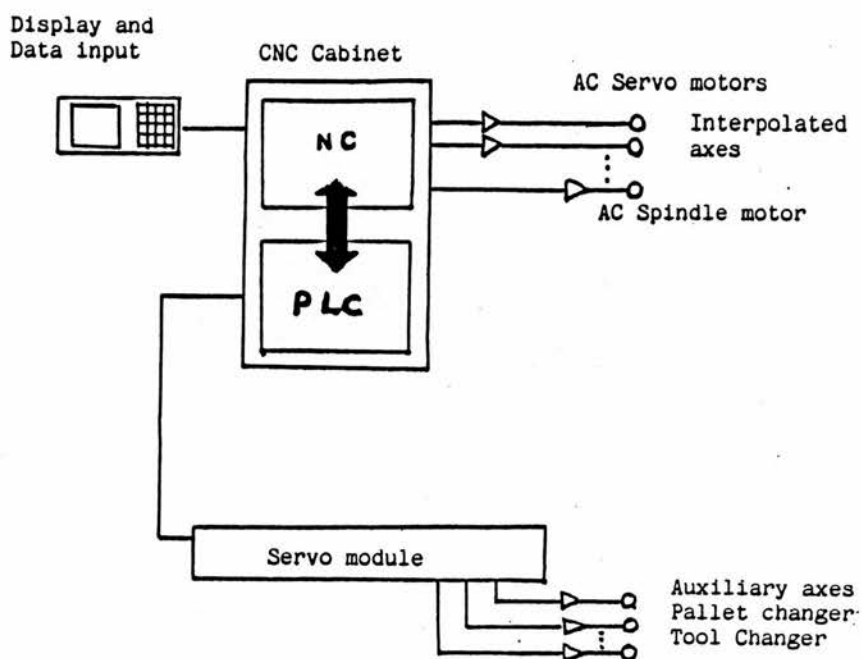


Figure 3.5- Layout of a CNC Unit

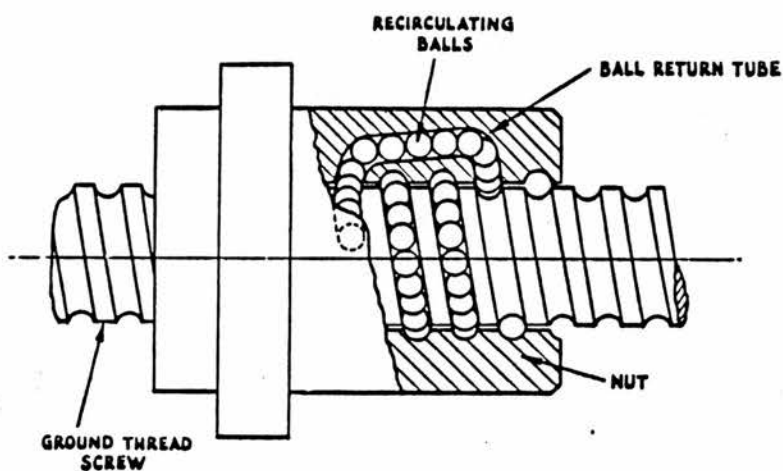


Figure 3.6 Recirculating Ball Screw

Further refinements of the CNC unit have been enabled by the miniaturisation of integrated circuits: the number of circuit boards used in the control unit has been reduced from 280 to one. While the number of discrete components was decreasing, there was a rapid rise in processing power contained in the unit. Large producers of control units are able to design and make customised large-scale integrated (LSI) chips for use in these units. LSI chips give a reduction in the number of semiconductors in the unit and make the system more reliable. Custom LSIs are used in the feedback loop, giving higher quality servo-control and improving machine performance, especially in areas such as thread cutting and circular interpolations. It is claimed that the introduction of the microprocessor reduced the price of the control unit by about 60% (Watanabe, 1983: 7). This reduction has also led to a steady decrease in the price ratio between CNC machine tools and conventional machine tools: the price ratio of CNC lathes to conventional lathes in Japan dropped from over 8:1 in 1974 to just over 3:1 in the early 1980s (Jacobsson, 1986: 11).

Major additional improvements to the control unit include:

(i) Data Input: As the control unit has the processing power to edit the program loaded in its memory, a keyboard and display screen are now standard on CNC machines. This enables manual data input (MDI), allowing the operator to view the program, edit programs easily, and write new programs straight into the control unit. Many control units now also have background programming facilities – the ability to insert and edit programs, while a different part-program is running on the machine and controlling a cutting operation.

(ii) Memory: Initially, CNC units used Read Only Memories (ROM), in which all software is permanently fixed. This was seen to be an advantage over the memories in mini-computers, for which expensive software had to be written (Hollingum, 1976: 31). Subsequently, there has been a trend to use Random Access Memories (RAM), which are more expensive but allow for the software to be re-written. The ability to change the software allows users to load their own processing "know-how" into the control system,

and permits more sophisticated systems to be controlled (Watanabe, 1983: 7). The introduction of bubble memories for the storage of system software (e.g., part-programs, macro-libraries, and utilities) has greatly increased the capacity of the memory. The bubble memory is only used for the storage of the system software, and programs are copied from it to the faster dynamic RAM for execution (Ránky, 1986: 191). The two main advantages of bubble memories are, firstly, that they are completely sealed and have no moving parts, making them highly reliable even in the harsh environments of the factory floor; and, secondly, that the memory is non-volatile, so the control unit does not need to have either continuous power, or arrangements for back-up power, as a precaution against power failure, in order to retain the contents of the memory.

(iii) Additional Features Controlled: An increase in computing power has made it possible to control more axes simultaneously. Many lathes now have four-axis control, and machining centres have five. Additional mechanical hardware has been added, including Automatic Tool Changers (ATC), pallet changers, and robotic arms to load and unload parts. All these features are also controlled or activated by the CNC unit. When ATCs are used, the control unit may also have a tool library which will record data on the tools, including the amount of use they have had. In the case of tool breakage, a similar or identical tool in the ATC may be substituted automatically. (Many of these features are discussed in greater detail in the next section.)

3.4 Design Changes

Standard conventional machine tools are estimated to be physically cutting metal for only 2.5% of their operating time (McPherson, 1979: 1). And the "average" workpiece on the "average" shop-floor undertaking batch production spends just 1.5% of its total time on the shop-floor being cut on a machine; the remaining 98.5% is spent being moved, loaded, positioned, and waiting (Sigurdson, 1986: 21). While CNC does not reduce the actual cutting time, if used efficiently it does increase the proportion of time that the machine is cutting metal. This increase is accomplished by reducing the number of set-ups and the set-up time, reducing workpiece handling, and, in some cases, speeding up tool changes.¹⁴ CNC machines may also increase the proportion of time the workpiece is being worked on while on the shop-floor. This leads to a decrease in work-in-process, the total inventory that needs to be carried, and the lead time for new products.¹⁵

The movements of the tool and/or workpiece on CNC machines are carried out much faster than on manual machines, resulting in more severe loading conditions on the feed mechanisms, motors and guides. The CNC machine also has to be fitted with sensitive measuring systems which need to operate continuously - even when the machine is taking heavy cuts - to provide feedback to the control unit. Therefore, CNC machine tools have to be designed for longer and more arduous periods of continuous operation than conventional machines. These considerations mean that the mechanical hardware of CNC machines has to be stiffer, freer from vibration, and more robust than that of conventional machines.¹⁶ A further consequence of the increase in cutting time is the increased quantity of swarf (the small pieces of metal that have been cut off the workpiece) that has to be efficiently removed from the machine to prevent blockages and jamming.

Wear is a problem on conventional machines, and the mechanical nature of the machine tool also results in lost motion. Both these problems result in inaccuracies which may be corrected to some extent by skilled machinists, who know the inaccuracies of the specific machines

with which they work. These inaccuracies cannot be efficiently compensated for by a control unit, and, therefore, the design of the machine has to be changed in order to reduce or eliminate them.

There have been significant changes in the design of components and the utilisation of new components in order to cope with these new requirements. Such up-graded components may be fitted to conventional machines to convert them to CNC machines, and this type of machine is known as a "retro-fitted" CNC machine tool. Alternatively, a totally new machine may be designed which is more suited to the special requirements of CNC.

3.4.1 Improvements in Components

Conventional machine tools use a screw turning in a nut to operate the motion of the table, saddle, and knee, and these screw threads are particularly prone to an inaccuracy known as "backlash".¹⁷ The screw mechanism is also very inefficient (often less than 25%) due to high frictional resistance between the flanks of the screw and the nut. This also causes an increase in the temperature of both parts, resulting in a further inaccuracy. A backlash eliminator may be fitted to the screw and nut, but this causes an increase in friction which further reduces the system's efficiency and increases its temperature.

On CNC machine tools these problems are overcome by the use of the re-circulating ball screw, in which the contact between the screw and the nut is achieved through an endless stream of steel balls. The assembly consists of a shaft with a semi-circular helical groove, a nut with a corresponding groove, and a set of precision ground steel balls which fit into the groove, as shown in Figure 3.6. The stream of balls is deflected through a return channel at the end of the nut, so ensuring a continuous flow. A single nut assembly of this type will still have some backlash, but this may be eliminated completely by using a double nut assembly and by pre-loading the balls. The efficiency of this mechanism is high, typically over 90%, and the temperature rise is low (Martin, 1983: 37). Because of these advantages, ball screws are used extensively in CNC

machine tools. Other losses come from the wind-up of drive shafts, the deflection of machine tool members, and the stick slip of slides. Many of the sliding components in conventional machine tools have been replaced in CNC machine tools by rolling components, in order to provide nearly friction-free movement, and to retain the alignment and close fit of the slide.

The castings used for the beds of CNC machine tools are generally more heavily ribbed than on conventional machines, making the bed more rigid. Additionally, the hollow space between the ribs and under the bed may be filled with moulding sand to damp down vibrations (Simon, 1973: 225). Some experimentation is being done on the use of concrete beds, which have a sheet-metal casing braced internally by steel rods and filled with concrete. Concrete offers advantages from its ability to damp vibrations and its greater thermal stability, which results in longer tool life, better surface finish, and the potential to retain accuracy over very long periods of continuous operation. The use of fabricated steel structures and granite for the bed is also being investigated (UNIDO, 1985: 39-40).¹⁸

On conventional machines, the main drive power is supplied by standard electric motors, which are connected through gear trains in order to change the drive ratios and hence the speed. For most machining and manufacturing operations, it only became possible to use numerical control systems with the development of the servo-motor. Servo-motors respond directly to an electrical signal and produce a constant torque, the motor speed varying linearly with the input current.¹⁹ Most servo-motors used on CNC machines are DC, but AC servo-motors are being developed, and they are likely to be used to a great extent in the future. AC motors require less maintenance than DC motors, but they are approximately 50% more expensive (UNIDO, 1986a: 59).

If feedback is not required, for example on the main spindle, a "steppa-motor" could be used. Steppa-motors are a special type of servo-motor which have the input command and the position of the motor synchronised. Because they may be controlled by an open loop system,

they have faster real-time control and eliminate the need for position feedback devices. In practice, steppa-motors are rarely used on machine tools as they do not have the power and range of speeds required. Steppa-motors are, however, used extensively on robots and on other transport and pick-and-place devices.

3.4.2 Changes in Machine Design

As the design of components used in machine tools has changed with the introduction of CNC control, so too has the overall design of the machine itself. A major development from the milling machine has been the concept of the machining centre. Like milling machines, machining centres may have a vertical or horizontal configuration, and they have the same basic structure as a milling machine, i.e., a bed mounted on a saddle, with the cutting tool mounted vertically or horizontally on a column. The machining centre is more versatile than the milling machine, being capable of drilling, tapping, reaming, boring, and milling. This enables the machine to perform many of the cutting processes required on one workpiece in a single set-up (rather than having to set up the workpiece several times on different machines for different cutting operations), thus giving a considerable saving of time. With the reduction in set-up time, the machine can cut metal for a much greater proportion of its operating time, so increasing its utilisation rate.

To undertake all the different types of cutting operations, machining centres need to be able to change tools automatically. On small drilling machines, it is possible to use a turret to store a limited number of tools. But this is not a viable solution for larger machining centres, as turrets would be far too large and heavy if they were to take all the tools required. There are two principal types of tool storage mechanism in general use: the tool carousel and the chain system. Tool carousels, sometimes referred to as drums, usually contain up to 30 tools. In the chain system, tools are stored in pots linked by a continuous chain. This second system is virtually limitless; chain systems can be linked in parallel, allowing storage of over 200 tools. Figure 3.7 shows a machining centre with the second type of tool storage. The tools are

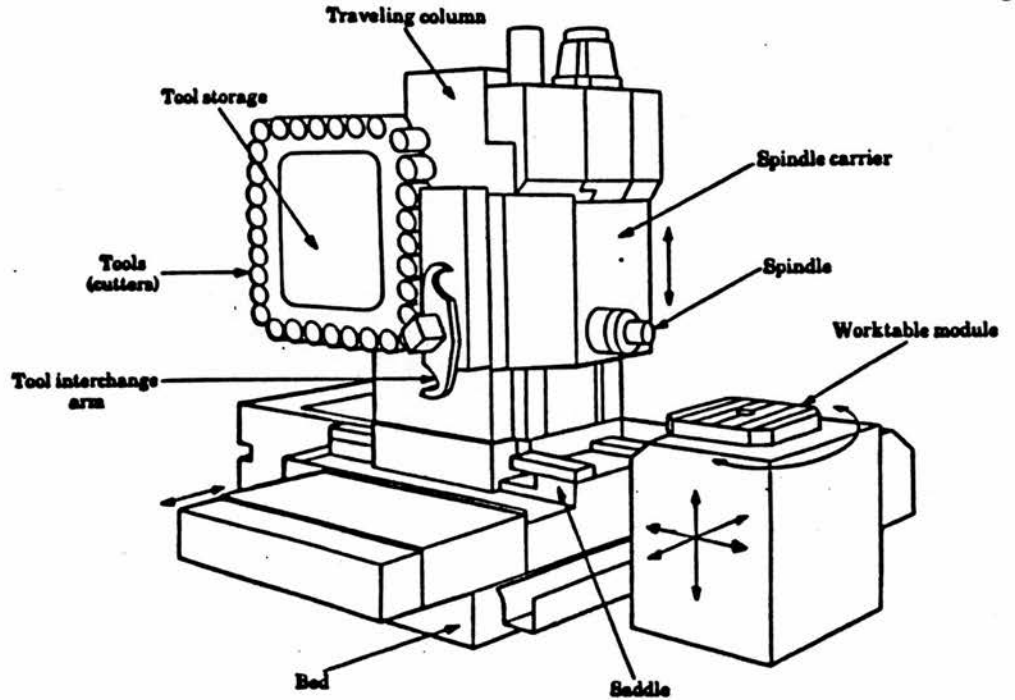


Figure 3.7 Machining Centre with Automatic Tool Changer

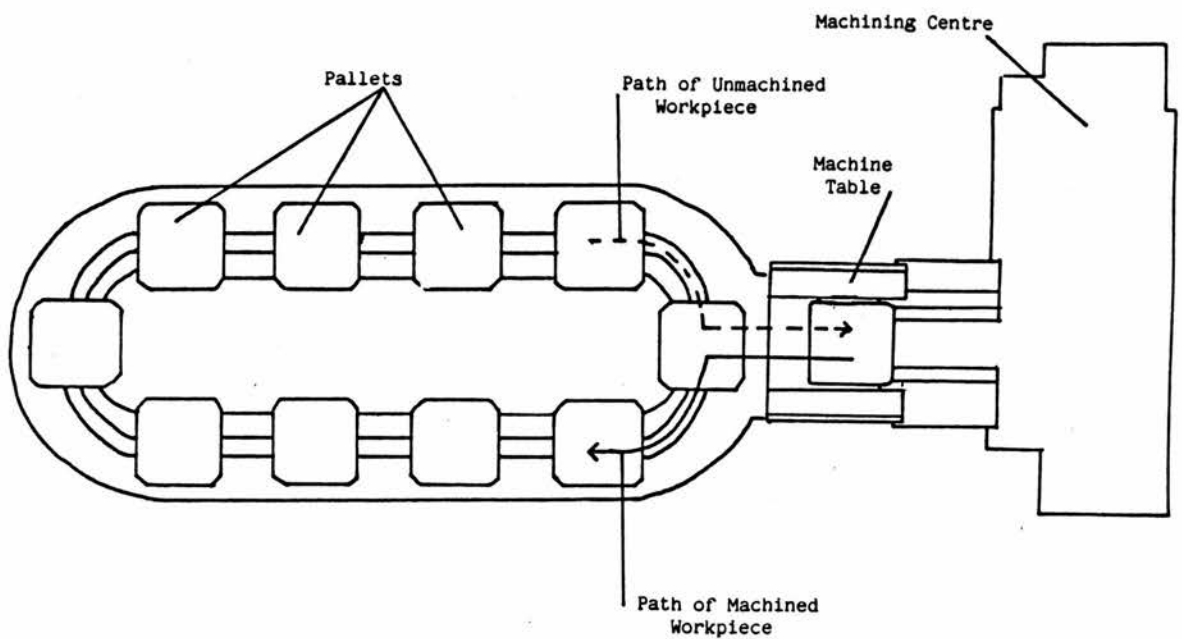


Figure 3.8 Layout of Machining Centre with Pallet Pool

changed by a simple mechanical arm which rotates about its centre, and has grippers at each end. The tool changer operates by taking the new tool out of the storage system, after which the arm is relocated so that it is within reach of the main spindle. It then removes the old tool from the spindle with its empty gripper, rotates through 180° , and places the new tool in the spindle. The old tool is then replaced in the tool storage system. The use of automatic tool changers (ATC) has considerably reduced the machining time lost in tool changing. The time taken for tool-to-tool changes can be as little as a few seconds, and the chip-to-chip time is, in some cases, less than ten seconds.²⁰

The flexibility of the machining centre has been further enhanced by an increase in the number of controlled axes from three to a possible five. The workpiece may be re-positioned by a rotating table, which enables the job to be machined on several surfaces in one set-up. A further axis can be added by the rotation of the spindle head, so that the machine may cut in both horizontal and vertical modes. The addition of these two axes means that if a cube of metal is fixed to the worktable, five of its six faces may be machined in a single set-up.

To further reduce the set-up time on machining centres, some machines have two work tables, or the ability to load and unload pallets on the work table. This enables the machine to continue cutting one workpiece while the last workpiece is unloaded and the next workpiece is being fixed to the work table. This system can contain only two work tables, which are operated alternately. However, some systems have pallet pools containing up to ten pallets. (This type of system is shown on Figure 3.8.) Not only does this increase in the automation of loading and unloading allow for increased utilisation of machining time, but periods of unmanned operation are also made possible.

In the case of the lathe, the major design change has been the development of the slant bed. Instead of the bed being horizontal, it is tilted at an angle between 40° and 65° to the horizontal. This configuration has two advantages. Firstly, it makes the machine more rigid in operation; secondly, swarf and used coolant are more easily

disposed of as they fall to the bottom of the bed, where they may easily be removed without interfering with the cutting process. As on conventional capstan lathes, the most common way of storing tools on CNC lathes is in turrets. Some machines have two turrets and are capable of machining both internal and external surfaces simultaneously. On early NC and CNC lathes with only one tool, two axes were controlled, the radial and the longitudinal axes relative to the workpiece. With the addition of a second tool, which also has to be controlled in the radial and longitudinal axes, four-axis control has to be used.

On some more advanced CNC lathes, the workpiece may be held rigidly and statically in the chuck while a rotating tool, such as a drill, machines it. This combines the traditional turning functions of a lathe with the cutting functions found on other types of machine. Lathes with these additional machining functions are often referred to as "turning centres".²¹ The addition of rotating tools increases the flexibility and productivity of the lathe. In some production areas this can eliminate the need for secondary machining, giving reductions in capital cost, work-in-progress, and setting-up time. As more cutting operations can be undertaken on a single set-up, errors from re-positioning the part, including the possibility of loss of concentricity, are reduced.

To further automate the operation of CNC lathes, robotic arms can be attached to the machine to load and unload parts. These arms are usually small and dedicated, and, because of their dedication, they are fairly unsophisticated and inflexible. Unmachined and machined workpieces may be stored in pools next to the lathe in a similar way to the pallet pools of machining centres, and are loaded and unloaded by the robotic arm. This capacity for workpiece storage and automated loading/unloading enables the lathe to run unattended.

3.5 Factory Automation

CNC is only one example of the many different applications of microelectronics control to equipment on the factory floor, in the office, and in the home.²² With the increasing availability and lower cost of computing power, and the development of more sophisticated software, the control of many machines may be coordinated. Kaplinsky (1984a: 24-28) divides the changing nature of automation into three distinct phases, as shown in Figure 3.9. In the first stage, intra-activity automation takes place within the three separate areas (or spheres) of production: manufacture, design, and coordination. Discrete functions within these spheres are automated, e.g., the control of a standalone machine tool using a CNC unit. In the second, or intra-sphere, phase automation technologies link activities within the same sphere. This includes DNC, where several CNC machines are linked to the same computer and Flexible Manufacturing Cells (FMC). An FMC consists of a CNC machine tool, a workpiece store, workpiece and tool handling devices, and automatic control. Thus, the machining centres and turning centres, with pallet pools, high-capacity tool changers and robotic arms, discussed in the previous section, can be considered FMCs.

Finally, activities in different spheres of production are coordinated, and automation is, therefore, inter-sphere. An example is the linking of a Computer Aided Design (CAD) system to a CNC machine tool, so that the design developed on the CAD system can be directly loaded into the control of the CNC machine: this is usually referred to as CAD/CAM. Inter-sphere activity also includes Flexible Manufacturing Systems (FMS) which contain several CNC machine tools and/or FMC. These are linked together by an automated workpiece flow system, enabling the simultaneous machining of different workpieces which pass through the system along different routes. These systems incorporate some production planning, so there are links between manufacturing and coordination activities. The most advanced example is the coordination of manufacturing systems, inventory control, warehousing, and design; this is often known as Computer Integrated Manufacture (CIM).

Figure 3.9 Spheres of Automation

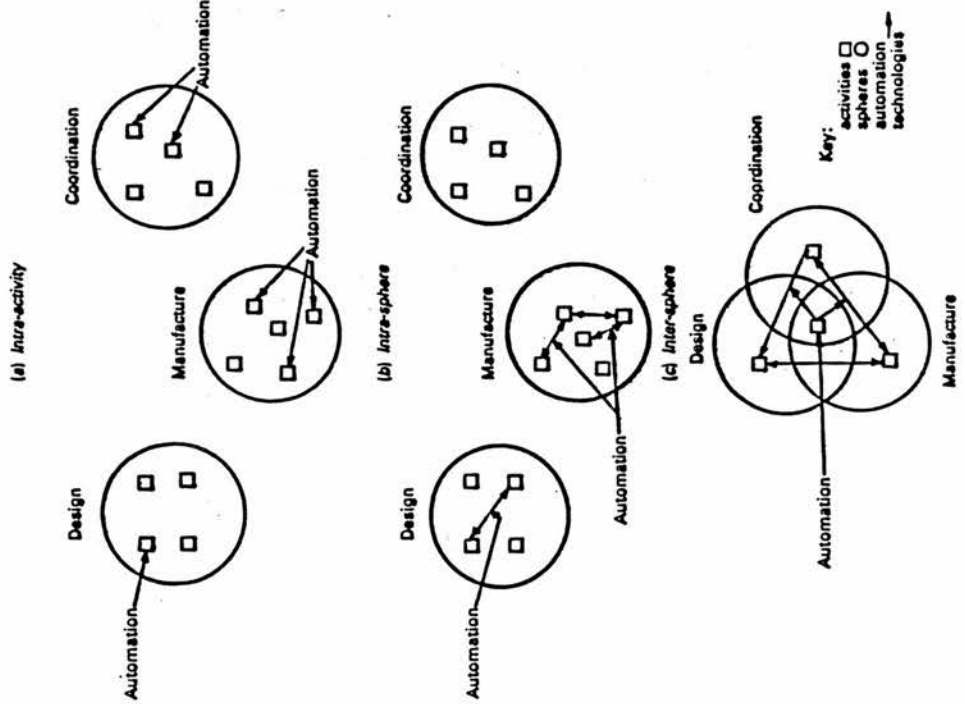
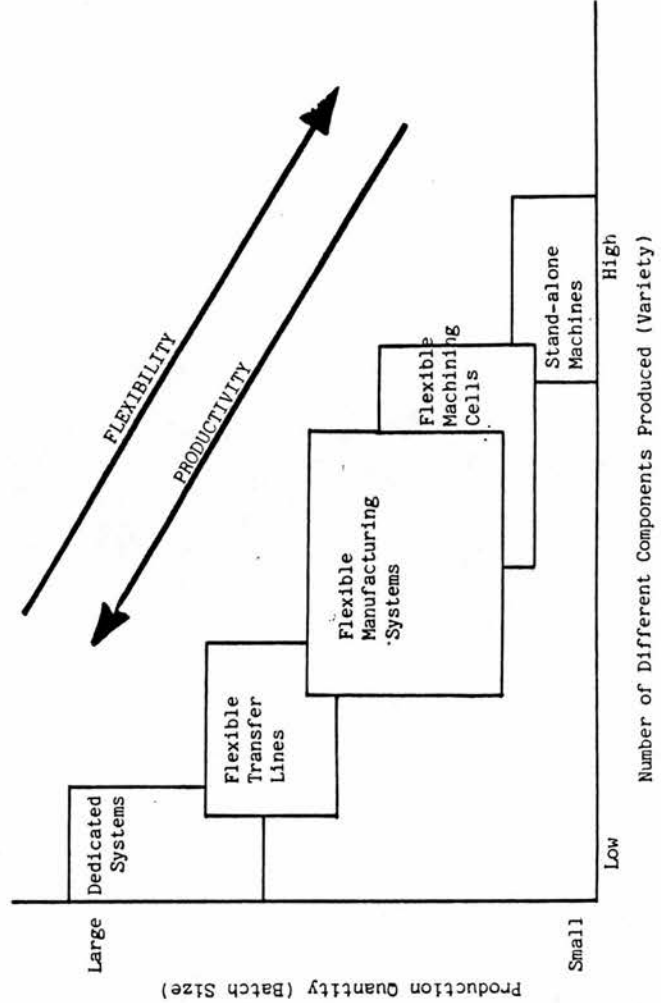


Figure 3.10 Types of Automation for Different Production Situations



The automation implemented by firms depends to a great extent on the type of production they are undertaking. There are two main variables influencing the way producers manufacture their goods: the scale of production and the variety of designs. Since mass producers typically make only a small range of products, whereas small batch producers manufacture a very large number of different products, the type of automation varies accordingly. (Figure 3.10 illustrates the different forms of automation applied for these production variables.)

Large-scale production makes it viable to use dedicated systems, or special purpose machines, which are only capable of producing one type and size of component.²³ Less dedicated systems, which enable the production of similar products with slightly different specifications, are known as Flexible Transfer Lines (FTL). These are made up of special purpose machines, or automated universal machines, linked in a line by an automated workpiece flow system. In these systems, different workpieces are machined simultaneously and run through the system along the same line. The variety of workpieces produced in these systems is small, usually less than ten variations of a similar part. Because of the difference in cycle and setting times for various parts, there may be buffers between the machines (Warnecke and Steinhilper, 1985: 4-5).

Small and medium batch production account for a very significant proportion of industrial output: it is estimated that in the US between 50% and 75% (in terms of value) of metal working production occurs in batches of less than 50. The production of goods in these small batches is far more costly than mass production; the ratio of costs may be as great as 100:1 (McPherson, 1979: 1). It is in this type of production area that FMC and FMS have been installed and where they have been most effectively exploited. Indeed, the availability of economies in batch production is a major part of the definition of FMS used by the UK Department of Trade and Industry:

Flexible manufacturing is a system which combines microelectronics and mechanical engineering to bring economies of scale to batch work. A central on-line computer controls the machine tools and other work stations and the transfer of components and tooling. The

computer also provides monitoring and information control. This combination of flexibility and overall control makes possible the production of a wide range of products in small numbers (Quoted in Edghill and Davies, 1985: 37).

The manufacturing philosophy of Group Technology (GT), originally developed in the USSR in the 1950s for organising production using conventional, standalone machines, is often used to decide which type of component is manufactured in a system. GT works on the principle that there are many families of components with similar configurations, which have to be machined in similar ways. Using this principle, the layout of machines on the work-shop floor is changed from having the same types of machines grouped together or in lines, to having several groups of different machines. Each group of machinery is capable of all the machining processes required on a certain family of components. Thus, instead of a piece of metal being moved around the factory floor for different machining operations, the part is machined completely in one area. This gives reductions in throughput time, work-in-progress, inventory, setting-up time, and work handling.

The first FMS was designed by Theo Williamson for Molins in 1962; it was known as the Molins System 24, as it was capable of 24-hour operation. The system was designed to cut various components for cigarette making machines. The components were all cut from a standard block of aluminium and the blocks were moved to different stations for different cutting operations (Bessant and Haywood, 1985: 11). As these parts were made of relatively soft aluminium, the system could not be used for cutting harder metals. This was one of the many reasons why the system was not widely adopted within the metal cutting industry. The main inhibiting factor to the system's development was that the control technology available at the time was very limited. Although the first FMS was produced in 1962, it was only in the early 1970s that FMSs started to be significantly developed and utilised, but their subsequent diffusion in manufacturing industry has been slow. Bessant and Haywood estimated that by the late 1970s the world-wide population of FMSs was less than 75, and by 1984 there were only about 200 (1985: 18).

Despite their name, FMSs have only limited flexibility. Systems can only machine a certain type of component, the size of which is limited by the size of the machines in the system. The number of possible machining operations is also limited by the types of machine in the system. This inflexibility is often caused by the fixtures used in the system to hold and transport the workpieces, and not by the machines themselves, which are capable of machining any shape within their size limit. Fixtures can usually only hold similar parts, and therefore limit the size and shape of the components that can be manufactured (McSherry and Hill, 1986).²⁴

According to whether prismatic or rotational parts are being produced, different methods of workpiece loading and transport are used. Thus, it is rare for an FMS to produce both prismatic and rotational parts and FMSs are more frequently installed for the production of the former. In Edghill and Davis's global study (1985), 85 out of a sample of 107 systems surveyed produced prismatic parts. Items principally chosen for processing in FMSs are mainly high-value critical components. And, as rotational parts are usually low-cost items, they are not generally considered for FMS production because it is harder to justify the investment costs (Edghill and Davis, 1985: 45-47).

FMS and FMC are important to machine tool companies not only as production methods, but also as product areas. Many of the larger machine tool builders have already expanded into the installation of FMS as a part of their manufacturing strategy, and others are manufacturing FMCs as well as standalone CNC machines. Most of these producers have installed such systems within their own manufacturing plants in order to learn more about difficulties in their design, installation, and operation. Indeed, one large Japanese producer has installed three FMSs, undertaking different types of work, to gain such experience. Producers also demonstrate these systems to potential customers. As a consequence, the machine tool industry is one of the largest users of FMS, in one survey almost a quarter of the sample of 80 FMSs were installed in machine tool firms (Bessant and Haywood, 1985: 21). Even for those producers which have not commenced the production of these systems, the requirement to

design standalone CNC machines that can be integrated into systems built by others is becoming an important consideration.

3.5.1 A New Focus in Manufacturing

A major concern of manufacturers has always been to reduce production costs and to improve product quality. Many firms are currently attempting to achieve these aims by the implementation of "Japanese manufacturing methods". The two main Japanese concepts that have had the greatest influence on the design of new manufacturing systems are Just-in-Time (JIT) production and Total Quality Control (TQC).²⁵ It should, however, be noted that these manufacturing methods are not technology dependent and can be implemented in plants using conventional or standalone CNC machines, as well as in those that have installed more automated systems.

The principle of JIT is that parts, sub-assemblies, and finished goods are only produced, or delivered, just before they are required in the production process. JIT is sometimes referred to as "stockless production", as its main aim is that all materials in the factory should be currently worked on, and stores of inputs, buffer stocks in production, and stores of finished goods should be eliminated. JIT has other implications apart from being an efficient inventory control system. JIT improves quality control and reduces the quantity of scrap, as it draws attention to faults as they occur, rather than finding them later. Further, the plant configuration may be streamlined to raise the process yield and improve production rates. To approach stockless production, a cut in batch size is required so that excessive buffer stocks which incur carrying costs are not produced. But the batch size must be large enough for the set-up costs for each batch to be economic. With this aim in mind, the designer must develop a system or production layout in which the changes required to alter set-ups for the production of various different types of components are negligible. In an ideal system, the economic batch size would be one, and the set-up time for parts would approach zero.²⁶

The goal of TQC is that quality in production should be continually improved and that there should be "zero defects". This is achieved by transferring quality control checks on parts from a specific department to the actual person manufacturing the part, and increasing the number of parts actually checked for quality. In some cases, all parts are so checked. In many FMSs, some form of measuring machine is often incorporated into the system, in order to check manufactured parts. Further, many individual machines are now equipped with their own probes, enabling them to measure a loaded part and ensure that it has been machined correctly.

3.6 Technological Capability Requirements for the Manufacture of Machine Tools

What technological capabilities does a firm need to manufacture conventional machine tools? How is the manufacture of CNC machines different from that of conventional machine tools and what new capabilities does the firm have to acquire to begin producing these machines? Two main areas of capabilities need to be considered: (i) those required to actually make machine tools, i.e., the skills and capabilities required on the shop-floor to make the component parts of the machines and to assemble them; and (ii) the capabilities used to design new machines and adapt existing ones. A major difference between conventional and CNC production is the use of specialist components, which conventional producers cannot, without considerable investment, make in-house. This difference means that the production of CNC machines is less vertically integrated than conventional production. For producers in industrialising countries, there are further consequences, as there can be difficulties in purchasing these components. These difficulties and the capabilities required to begin the indigenous production of some of these specialist components will be discussed in this section.

3.6.1 Production Capabilities

In a conventional machine tool factory, the majority of the work undertaken on the factory floor consists of the casting and machining of the bed, the general machining of parts, and the assembly of these parts to make the machine tool. A basic requirement of machine tool manufacture is the availability of cast-iron and the existence of foundry facilities for casting the machine bed. Many machine tool producers have their own foundries, but it is also common for firms to sub-contract this work. The surfaces of the bed on which slides are positioned have to be machined, and it is critical that these surfaces are flat. As the bed is too large to be worked on standard machines, machine tool producers use large plano-millers and grinders to cut these surfaces, but producers making fairly small machines can file and scrape them by hand if they do

not have the capital to invest in the larger machines. Although the quality of the surface finish obtainable by machining is fairly high, the surface is often finished by hand scraping, and this is particularly common in the manufacture of special purpose machines. Slideways can then be positioned and ground on the bed.

Many other small mechanical components also have to be manufactured. These include the head and tail stocks, tool holders, the chuck, and, for conventional machines, gear trains enabling running speeds to be changed. This work includes gear cutting, milling, turning, and grinding. Some components may also need to be heat treated in order to improve their durability. As well as the casting work, some component manufacture and heat treatment may be sub-contracted to other firms. For some of the sub-contracted production work, it may not be viable for the individual firm to invest in the necessary capital equipment, or the sub-contractor may be able to obtain a higher quality finish than the machine tool firm can achieve in-house. The machine tool making firm will routinely buy in some components, including all the electrical parts, e.g., motors, lubricant pumps, electrical wiring, and switches.

While the firm may be able to sub-contract a large proportion of this preliminary production work and buy in many parts, the final assembly must be undertaken in-house. For many products, assembly skills are fairly trivial, but, in the case of machine tool manufacture, they are an important element in final quality and performance. Sub-assemblies, such as the gear boxes and head stocks, are made and tested before the whole machine is assembled. If the machine tools produced are to be accurate in operation, they must be built with all parts in alignment and adjusted with great care during assembly. Once assembled, the machine has to be rigorously tested and further adjusted to ensure that it will remain accurate in long-term use.

In the conventional machine tool plant, semi-skilled workers are employed to work in areas such as material movement, basic machine operation, loading and unloading, and some basic fitting and assembly. The major technical requirement for these workers is that they know how

to use measuring instruments and to read engineering drawings. Skilled workers are principally employed to operate metal working machine tools, to undertake quality control, to assemble high-precision components, and to fully test and adjust the finished machines (UNIDO, 1986a: 26). Traditionally, these skilled workers require several years of apprenticeship, usually between three and seven, to learn their skills. Skilled employees have considerable knowledge of the operation of machine tools, including tooling technology and machine calibration. They are also able to maintain and undertake minor repairs on conventional machine tools. Skills built up from operating, repairing, and rebuilding machine tools may be utilised in the assembly of new machines. A very large proportion of these skills is readily available in the general metal working industry, and it is therefore fairly easy for producers in the metal working sector to enter conventional machine tool manufacture.²⁷

All the skills just described are also used in the production of CNC machine tools, but the quantity of component production is considerably reduced. This is due to two changes: firstly, many special mechanical components are bought in by the firm from specialist producers (e.g., the ball screw), and, secondly, there are fewer components, as all the mechanical controls and some gear boxes have been eliminated by the introduction of the control unit and variable speed servo-motors. The total number of components used in the manufacture of a CNC machine tool has been reduced by 30-40% (Watanabe, 1983: 28).

The skill area which has changed most, and in which capability demands have been most increased, is assembly. Sensing devices have to be fitted to the machine, carefully aligned with the slideways, and connected to the interface. The commissioning of the machine is also more complex, necessitating tests on the electric drives and the CNC system. While the experienced user and repairer of machine tools will have few difficulties in beginning conventional machine tool production, for the manufacture of CNC tools there is a production barrier confronting the conventional producer. Firms have to acquire the new skills required to make the electronic circuits in the interface and the electrical wiring to join the interface to the sensors fitted on the

machine. (Similarly, there are increased demands for electrical and electronics capabilities in the design of CNC machine tools, and these are treated in detail below.) Although most CNC producers gain operating, but not repairing, experience of CNC machine tools on their own shop-floor before commencing CNC production, these skills are only of limited use in the final assembly and testing period.²⁸ Chapter 6 notes that several Korean conventional producers, with many years' experience in that production sector, encountered considerable difficulties in the production and assembly of CNC machines. These problems were, in the main, overcome by the training of personnel overseas, the employment of consultants, or through the technical support accompanying a foreign technology agreement.

For producers entering the manufacture of FMCs and FMSs, there will be an increase in assembly work and in the number of components produced. However, the technical skills required to manufacture these parts are not significantly different from those used in making of CNC machine tools and, therefore, should not be a problem for the firm to acquire. Some components in the system may be bought in from a specialist producer rather than produced in-house, e.g., robotic arms for FMCs and automated guided vehicles for FMSs.

Finally, it is necessary to consider the changes in skills required in the repair and maintenance of CNC compared to conventional machine tools. These concern machine tool producers both as machine users and machine vendors. On conventional machine tools, most repair and maintenance work can be undertaken by the skilled machinist, and, in a mechanical work-shop, simple machine tools can be dismantled, reconditioned, and rebuilt. In fact, many machine tool producers originated from firms which were machine tool users, and built their first machines using the experience they had gained from using and repairing machine tools. Thus, for conventional manufacturers, existing skills within the firm are adequate to repair and maintain their own production equipment, and, as most machine tool users can undertake basic repair and maintenance work, there is no significant requirement for producers to offer after-sales services to their customers.

The situation is entirely different in the case of CNC machine tools. On these machines, the operator is only able to undertake a small proportion of repair and maintenance work. Skills in trouble-shooting on CNC machine tools, the repair of the electronics components, and the correction of software faults are all new skills that have to be learnt. As the majority of CNC machine tool producers buy in control units from specialised producers, they cannot easily build up these skills themselves nor can they supply after-sales services of control units to their customers.²⁹ The specialist controls producer or its agent is the usual source of back-up repair and maintenance service. However, in industrialising countries this can still be a problem, as controls producers will not establish such facilities until there is a certain level of use of their controls.³⁰

3.6.2 Design Capabilities

The distinction between the roles of skilled and semi-skilled workers in production is mirrored by a similar division in companies' design departments, where the corresponding types are usually designated as "core designers" and "detail designers". Core design involves the development of the original machine tool concept, its layout, and its basic specifications. Thus, all the originality and new innovations included in the design of the new machine are the responsibility of the core designers. Although core designers do not form the largest proportion of firms' design personnel - often less than 25% - they are, nevertheless, vital for innovation. The type of work undertaken by core designers will to a large extent depend on the product strategy of the firms in which they work. Designers may solely copy existing machines, and in some cases simplify their designs. (This was referred to in the previous chapter as crude copying.) Some adaptations may also be incorporated in the copying process (adaptive design), or the design may be an enhanced version with new innovative features (developed design). Finally, the design may be totally innovative (new design). In the main, most design work undertaken by machine tool producers is of either the adaptive or developed type. The work of detail designers involves

drawings, specifications, and assembly diagrams for all parts of the machine, including the detailed design and assembly of small mechanical components. Many of these designers are draughtsmen working to the original ideas and drawings supplied by core designers.³¹

For the conventional producer, the skills of design personnel (both core and detail) are principally in the area of mechanical engineering, including some work with hydraulics (and/or pneumatics), and, to a lesser extent, metallurgy and tooling. If the firm produces many special purpose machine tools, demands on both core and detailed designers are greater, as new or altered designs have to be made so that the machines fulfil the specifications agreed with the purchaser. Many of these machines are custom designed and built, so the demand for design manpower is high, and such work utilises designers skilled in only certain aspects of the machine, e.g., cam design. In general, the design of such machines is only undertaken by firms with considerable design experience. Clearly, firms undertaking a large proportion of special purpose or custom design work will need to have much larger design departments than those which only manufacture standard machines.

There are two different approaches to the design of CNC machine tools. One can either retro-fit a control unit onto an existing conventional machine design, or one can design a new model specifically for CNC control. When producing a retro-fitted design, new motors, sensors, and leadscrews must be fitted to the existing machine, necessitating minor alterations. Specifications for the new components must be decided upon by the core designer(s), and these components have to be acquired. If a new model is to be produced, changes in the structure and configuration must be incorporated into the new design. The overall design of this type of CNC machine tool is more difficult for the new entrant. New cast-iron beds have to be designed and tested and moulds need to be made. Not only are these beds a different shape but they also need greater rigidity than beds for conventional machines in order to withstand the increased stresses that occur with the higher acceleration and deceleration made possible by the use of new motors. New machine parts, such as automatic tool changers, also have to be

designed. Friction in the machine must be minimised, and the machine has to be consistently more accurate in operation, since the operator of CNC machines cannot correct for any inaccuracies. These changes in the operating parameters mean that many standard parts and sub-assemblies used in conventional production have to be completely re-designed. In the case of machining centres and four-axis lathes, the mechanical designs are also considerably more complex as they involve the movement of parts in more axes. For the experienced core designer of conventional machines, the design of the mechanical parts of the new CNC machine should not present insuperable difficulties. Knowledge of the operation and mechanics of other CNC machines will obviously be advantageous to the CNC designers, giving them a better understanding of the operating principles of the new machine.

In conventional machine tool design and production, electrical work involves the design of circuits to link the motors on the machine to the control panel. Such design is fairly basic; consequently, conventional producers do not need highly trained or skilled personnel in this field. In CNC production, there is a requirement for some electronics design. Although firms usually buy in the control unit, containing all the complex circuitry, they still have to undertake some design work to attach the control unit to the machine tool. The circuitry involved is known as the "interface", and usually consists of ladder relay circuits using basic logic. Interface design is specific to the model of machine tool, since it has to take into account the types of sensors being used and the operating parameters. In order to design interfaces, some electronics skills must be acquired. Machine tool producers are, however, frequently given technical support in this design area from controls manufacturers, who often train personnel from the machine tool firms. The controls suppliers sometimes also help with the choice of specifications for other electrical components, i.e., the motors and sensors.

Core designers of CNC machine tools should in practice be able to develop the automated materials handling parts required for FMCs and FMSs. The design of these systems will, however, involve the firm in a much greater proportion of electronics work and some computing. At the

initiation of the project, there will be considerable work in production planning and finding an optimal layout for the system. This planning stage can draw heavily on computer analysis in order to test various layouts and production schemes. In the construction of the system, there is a much higher proportion of electronics design in order to interface all the components of the system to the main controller. If the machine tool firm is buying in the controls system from a major producer, it can collaborate with that supplier in this design field. Finally, in order to implement production planning, software for the system controller needs to be written. Again, this can be undertaken by the machine tool firm or the controls supplier. As the development work involved in such systems incorporates many more core designers from different disciplines, the firm needs to be able to effectively manage such a development group.

The design requirements of standard conventional machine tools should not create major difficulties for firms with engineering capabilities. The skills that have been generated in the operation, adaptation, repair and re-building of the company's existing stock of machine tools can easily be utilised in the initial design and production of machine tools. The design of more specialist conventional machines (for example, special purpose machines in which very high accuracy is needed) will require a greater build-up of core design skills, people who are experienced in machine design. Hence, entering specialist sectors of the market will be more difficult.

The core design capabilities used for conventional machine tools may also be used in the development of the mechanical elements of a CNC machine. However, while these skills are certainly adequate for the design of retro-fitted CNC machines, in order to develop new CNC machines designers need more information and experience of the operation of machine tools designed specifically for CNC control. Furthermore, these machines can rarely be designed by a single person, as new skills in electronics and electrical engineering are a requirement. Thus, an interdisciplinary team is typically involved with the development of new CNC designs. Conventional machine tool producers do not have personnel with these skills, nor are they generally available on the NIC employment

market, and this requirement may create some problems for conventional producers during the entry stage.

Whether conventional or CNC machines are involved, a firm wishing to undertake more than the crude copying of imported machinery critically requires core designers. Core design skills evolve within firms as personnel gain more experience in machine design and knowledge of the principles of machine tool operation. NICs will not usually have a large pool of such people and, since they rarely move between firms, direct recruitment of these types of personnel is virtually impossible. This is a major difficulty for all firms and the only long-term strategy enabling a company to overcome the scarcity of these skills is active encouragement of their in-house build up.

If firms do not have sufficient in-house capabilities to design new machines, there are several different measures they can take. The various learning methods described in the previous chapter can be used to accelerate the development of in-house capabilities. Firms can also collaborate with government-funded research institutes, in which a nucleus of such skills has already formed. In the development of electronics skills, it has already been noted that the controls suppliers themselves are often a key source of new capabilities. These are, however, short-term solutions for such firms, and there is an unavoidable need for them to build-up some level of their own design capabilities.

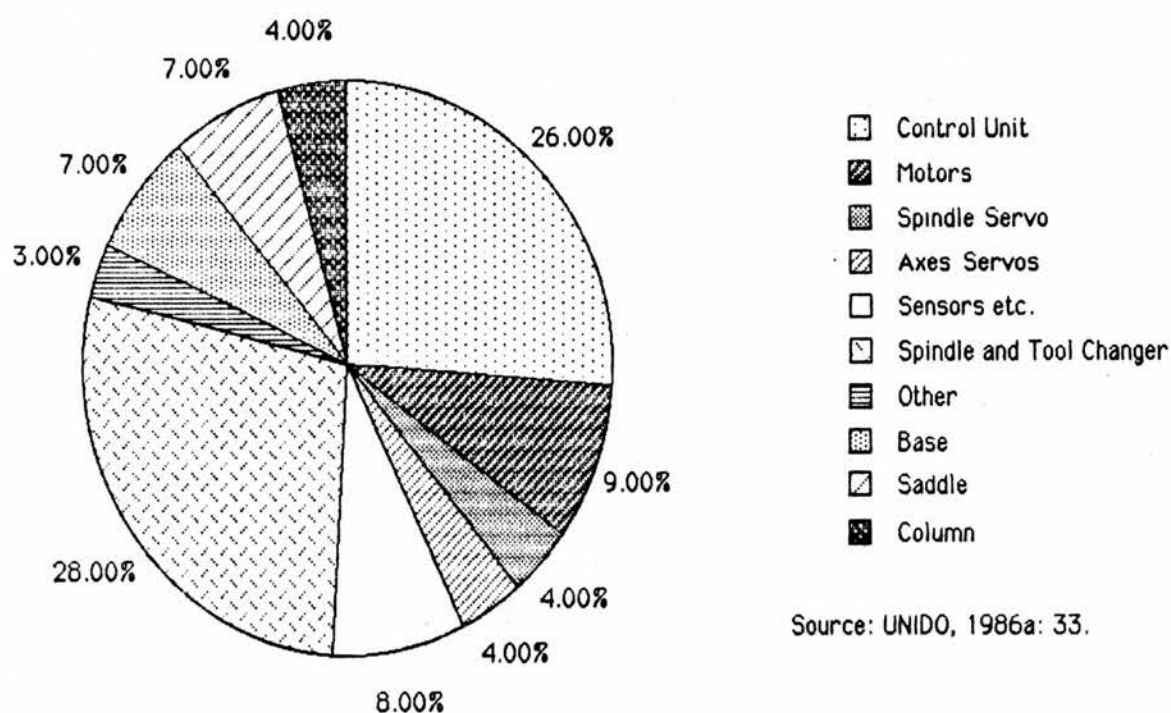
3.6.3 Component Manufacture

Traditionally, the conventional machine tool industry is vertically integrated. The firm produces the majority of the mechanical parts it uses, sub-contracts very little, and only buys in a relatively small number of components. A firm's principal material requirements are cast-iron, and a small quantity of high-grade specialised steels, used for some of the moving parts, such as the spindles and slides. The firm also needs a supply of standard motors, switching gear, and cables. All of these requirements should be readily available in a country with some established engineering production.

This chapter has already discussed the new types of components used in CNC machine tools. The majority of these components are produced by specialist firms and not by the machine tool manufacturers themselves. In terms of cost, the main bought-in components are the control unit, servo-motors, and ball screws; lower-cost components include sensors, cables, special couplings, and bearings. The cost structure of a machining centre is shown in Figure 3.11. Combined, the bought-in components typically account for about 50% of the final machine tool cost. But the proportion can be as high as 75% if some simple machining and manufacture of sub-assemblies is sub-contracted out. (The proportion does vary depending on the type of machine being produced. In general, a larger proportion of the final cost of a CNC lathe is accounted for by bought-in parts than a machining centre, as less assembly and machining work is undertaken by the machine tool firm in its construction.) Because of the importance of these bought-in components, the CNC machine tool industry, unlike the conventional industry, is not highly vertically integrated. Moreover, the work undertaken within the machine tool firm has changed substantially with the reduction in the amount of component production. Thus, the main emphasis is on the design of the machine and its final assembly.

For firms in industrialising countries, the purchase of specialised components is fairly easy, but in NICs these are not always readily sourced. NIC firms entering CNC production have to establish links with suppliers and make arrangements for the importation of such parts. This considerably extends the lead-time for developing a new machine, and, with the added difficulties in discussing specifications with the supplier, there is always some risk that an inappropriate type or size may be ordered. These difficulties are particularly great for the first entrants in a NIC, but as links are established, component importation may become easier. Of course, the NIC entrant firm may not help a competing firm establish contact with its supplier. But suppliers are more likely to either appoint an agent, or, as in the case of controls suppliers, set up a sales and after-sales facility in the country concerned once some demand has been established.

Figure 3.11 Cost Structure of a Machining Centre



Source: UNIDO, 1986a: 33.

Having to import a large number of components has financial implications for NIC firms, which often have to pay a much higher price for their components than producers in countries where there are indigenous suppliers. Jacobsson notes that the price of the control unit to special or large consumers may be reduced by as much as 50%, and that of mechanical components by up to 20% (1983: 200). NIC producers may be able to obtain part of this discount if they buy in large quantities. Furthermore, as the labour content of the final CNC product is relatively small compared to conventional machine tools, NIC producers are unable to make up much of this differential from their lower wage rates.

The most critical, complex, and expensive components of a CNC machine tool are, mechanically, the ball screw and, electronically, the control unit. If these components were to be made indigenously, there would be a further set of material and skill requirements. Ball screw manufacture necessitates the availability of suitable high-quality steel to make the lead screw, and the special purpose machine tool which can cut the helical grooves in the screw with the required precision. The assembly of ball screws requires a clean area to ensure that dirt does not enter when the balls are being loaded into the nut: this would impede the operation of the ball screw and increase wear, shortening its operating life. These three requirements should not be too difficult for engineering firms or machine tool producers, the major obstacle being the large investment required in this area of production. The special machine required to cut the helical groove is expensive. Therefore, in order to establish ball screw production, there needs to be substantial existing domestic demand. This applies to the production of many of the other mechanical components used in CNC machine tools.

The skills used in the development and production of control units belong to the disciplines of electronics design, electronics manufacture, and software engineering. The control unit has to operate in "real time", i.e., the response of the control unit has to be related to the time taken by the physical process, so that the results of the computation are available to instantaneously guide the machine. Thus, most of the control functions are in the operating hardware of the system and cannot be

written in slower operating software. Because of these requirements, the system architecture of control units is custom designed and customised chips need to be produced. As there are different numbers of axes and functions to control on different types of machines, control units are designed specifically for lathes, machining centres, grinders, or special purpose machines. Production of these customised large-scale integrated chips requires a high level of electronics design skills and access to chip fabrication facilities. For these reasons, it is very difficult for all but the largest machine tool producers to enter control unit production. Only developments in faster operating software and cheaper customised and semi-customised chip fabrication will reduce these barriers. Simpler control units can be produced using standard chips, but, in order for them to operate in real time, fewer functions can be controlled. Entry into the production of this type of control unit is obviously easier, but the potential market is small, as these controls are only suitable for use on the most basic machines.

Indian analysts have asserted the need for indigenous production of all critical components, including the control unit. They see the absence of such indigenous production as a constraint on the development of their CNC machine tool industry (CMTI, 1983: 92). However, Chapters 6 and 7 will document that the Korean and Taiwanese machine tool industries have successfully proceeded without indigenous control unit production. Although there have been attempts to develop control units in both these countries, at present virtually all controls are supplied by Japanese producers. Korean government and industry thinking recognises the eventual advantages of developing indigenous controls production. Yet they also recognise that at present the Japanese technological lead is practically insurmountable. As relevant electronics and software skills develop elsewhere in Korean industry, so Korea may, in future, possess the capability base that would allow successful entry into controls production.

However, the ability of the Korean CNC machine tool industry to perform its major function of supporting the manufacturing sector has not been compromised by its present limitations. That industry, as well as

the Taiwanese, is able to secure its supplies from Japanese producers. Arguably, there may be a price to be paid. Japanese producers have competed to sell controls on the Taiwanese market, largely because of those producers' export orientation towards the US. But the emphasis the Korean industry has put on manufacturing for its domestic market has meant that there has been less competition between Japanese controls producers in this market. Thus, the price the Koreans pay for their control units is somewhat higher. Nevertheless, even that situation may be subject to rapid change. It is plausible that, as the Korean market expands, there may be increasing competition in this market among Japanese controls producers, with corresponding effects on price. Additionally, there were signs that the Korean CNC producers themselves were starting to import controls from other suppliers.

The introduction to this chapter argued that industrial development depends crucially upon the acquisition of a relevant set of technological capabilities. Which capabilities need to be acquired similarly depends upon the nature of the technologies concerned. Design and production capabilities may be differentially difficult for an industrialising country to obtain. Yet the entire range of capabilities may not need to be acquired for a country to successfully enter CNC production and, indeed, the experiences of both the Korean and Taiwanese industries discussed below establish that case. The capabilities which appear to be essential for long-term development are those involved in design, interface development, and final assembly.

Notes

1. Machine tools can be divided into two general categories; those which cut metal and those which form metal. This thesis concentrates on the manufacture of metal cutting rather than metal forming machines, since the former category accounts for a much large proportion of all machine tools manufactured. (In 1986 metal cutting machines accounted for over three-quarters of all machine tools produced American Machinist, Feb. 1988: 63.)
2. For a more detailed explanation of the operation of all types of metal cutting machine tools, see How Things Work (1972, 2), and Boothroyd (1981).
3. Metal cutting machines before this time had mainly been used for the production of armaments, especially the boring of cannon, but these tools were too inaccurate for the production of components for steam engines. For more details of the early development of machine tools, see Rolt (1965), Galloway (1965), and Gilbert (1965).
4. "A cam is a specially shaped component that serves to guide the motion of a component called a follower": How Things Work (1972, 2: 212). A camshaft has several cams spaced along its length to control different operations; these may be either differently shaped cams or the same cams at different orientations.
5. For more details of non-traditional metal cutting processes, see Snoey's et al. (1986).
6. A form of tracer device had been used in the early eighteenth century in Sweden to manufacture long and heavy iron leadscrews for lathes (Rolt, 1965: 63-64).
7. Noble (1979, 1984) also thoroughly documents the development of servomechanisms and their subsequent application to machine tools. Additional information is drawn from American Machinist (Nov. 1977), which also contains details of other automation systems developed at the same time.
8. Noble also notes that Parsons was not the only engineer to develop digital methods of machine control in the immediate post-War period. In the early 1940s, the Kalkulex computing system developed by Killian was applied to a milling machine to control two of its axes automatically. This work was in part sponsored by a large US machine tool producer, Kearney and Trecker. Stibbitz, at Bell Labs, designed a control system which used sample data feedback provided by a commutator. The system controlled one axis on a cam cutting milling machine. In 1950, Cunningham, at Arma Corp., demonstrated a lathe on which the position of the tool, and the speed of movement to that position, were both controlled by wide-punched paper tape. With the outbreak of the Korean War, Arma Corp. stopped work on the lathe, but the firm later used a similar system to produce non-circular gears for the military. To control this gear cutter, 16mm film was exposed and, in the control of the machine, the film was

projected onto a battery of photo-electric cells. The preparation of the film took 100 hours for a typical gear. In 1949, an automatically controlled programmable lathe was designed and built by Carruthers. This lathe used special stepping switches and relays. The control system was programmed by rearranging electrical connections between the switches and relays, initially by re-soldering the connecting wires in different configurations. Because of the impractical nature of the re-programming, a plug board was used, and this method was subsequently replaced by a tape reader using 35mm film. While all these systems were used to some extent within the firms in which they originated, they were not developed past the prototype stage and were never commercially available (Noble, 1984: 86-93).

9. Feedback has been used in control mechanisms for centuries. Probably the simplest, and one of the earliest, examples is controlling the water level in a cistern with a ballcock. The ballcock opens a valve when the water level falls below its upper limit, and water flows into the cistern until the water regains its upper limit, when the valve is shut by the ballcock. In the steam age, mechanical speed governors were extensively developed to regulate running speeds. Early industrial applications of control with feedback took place in the continuous process industries, where mechanisms were used to control variables such as temperature, pressure, and flow rates. Initially, these controls were based on pneumatic and hydraulic techniques, and later on electro-mechanical devices. The development of electronics and basic electronics components - such as phototube amplifiers in the 1930s, followed by large electronics projects in World War II, and the introduction of the transistor by Bell Labs in 1947 - led to the emergence of electrical servomechanisms. Many advances in the theory and practice of electrical servomechanisms were due to military projects, notably the project at MIT's Servomechanisms Lab. to develop a radar-directed gunfire control system.
10. It should however be noted that the term NC is often used to refer to both NC and CNC machines. This is the case in both Japan and Korea, where NC is generally used to describe all machines fitted with control units.
11. For details of sensors used on CNC machine tools, see Ránky (1986: 174-85).
12. Part programs contain the information which describes the geometry of the cut to be made in the workpiece and the steps by which it is to be machined. These programs are usually written in a special language (known as APT) developed for use in NC and CNC control units. See Simon (1973: 430-37) for a description of APT and its development.
13. For more details of the system architecture of CNC units, see Ránky (1986: 189-93).

14. Reductions in setting-up time and workpiece handling stem from the increased accuracy of the machines and the reduction in the use of fixtures to position the workpiece. This results in further economies, as fixtures are expensive to design, make, and store.
15. For an analysis of the economic considerations of using standard, turret, automatic, and NC lathes, see Huq and Prendergast (1983: Ch. 4). For the financial (and other) considerations of installing CNC machines instead of conventional machines, see American Machinist (Oct. 1981: 185-92).
16. In general, the stiffness and rigidity of conventional machine tools have been improved in response to the development of high-speed cutting tools, which increased the stresses in the machine.
17. Backlash is caused by the play between the screw thread and the nut when the direction of movement is changed. As the screw changes direction, it will turn a small amount before the other flank of the screw engages with the nut. The loss in motion is therefore irregular.
18. Granite is at present used for the beds of co-ordinate measuring machines which need to have a very flat and stable base, but it is considered too expensive for use on standard machines.
19. This is achieved by varying the voltage supplied to either the inductor or the armature to control the motor. For a more detailed explanation, see Coiffet and Chirouze (1983).
20. These tool-to-tool and chip-to-chip times are taken from publicity material supplied by Japanese machine tool producers.
21. For a detailed review of turning centres, see American Machinist (Feb. 1985: 97-116).
22. For a more detailed summary, and technical information on the applications of microelectronics, see Forester (1980, 1985), Bessant et al. (1981), Scientific American (Special Edition on Automation), Sept. 1982.
23. The utilisation of dedicated systems is to some extent being eroded by two trends in the market for mass-produced items. Firstly, the product life of commodities is being shortened, meaning that machinery installed must be flexible in the long run. This is often achieved by making the tooling flexible, so that it is relatively easy to re-tool the system to produce an up-dated version or a new, but similar, product. Secondly, a greater number of varieties of the finished product are being offered, so that there is more variability in some of the parts produced and a reduction in the batch sizes of these parts. For this type of production, systems need to have built-in flexibility.
24. In his survey of 60 Japanese and 35 US FMSs, Jaikumar (1986) suggests that the Japanese systems are far more flexible (on

average each Japanese system produced 93 different parts while those in the US only made 10). He also found that the Japanese systems were more reliable and better integrated into the factories in which they operate. He argues that the major reasons for Japan's lead stems from the different approach taken by management.

25. Schonberger (1982) describes Japanese manufacturing methods, their application and advantages. He also notes that total quality control was, in fact, first used by an American, A.V. Feigenbaum, but that it was Japanese producers which first managed to implement it in their factories (1982: 47). Chapter 7 considers the effects of using these manufacturing methods on competitiveness, especially in international trade.
26. Of course, the ability of JIT to fulfil these ends is absolutely dependent upon availability of materials and component supply. If that supply should be interrupted, then the consequences for the plant may be disastrous.
27. Entrance into machine tool production by either machinery users or small workshops which repair and maintain machines has been a continuing feature of the industry. Floud's study of the British machine tool industry between 1850 and 1914 notes that:

The frequency with which machine tools were made in conjunction with other products suggests that entry into the machine tool industry must have been relatively easy for firms already established in other branches of the engineering industry, at least in the sense that most engineering firms would be technically competent to produce machine tools, even if they did not have particular commercial or design knowledge of the problems of machine tool production (1976: 42).

28. Frequently, firms will buy one or more CNC machine tools and use them in their own production plant in order to learn about their design and operation before they begin their own production. This is a situation similar to that of CNC producers installing their own FMS before they commence producing them for other firms.
29. For firms with at least fifteen CNC machines, it may be economic to acquire skills in the repair of electronics components.
30. As there is a large capital outlay involved in the purchase of a CNC machine tool, it is important that any downtime, due to machine failure, is minimised. A network of after-sales and service facilities must, therefore, be established by machine tool suppliers (including agents).
31. For a distinction between core and detailed design in relation to different types of work undertaken, see, for example, Westphal et al. (1984a: 8).

CHAPTER FOUR

The Global Machine Tool Industry: Its Structure and Trading Patterns

4.1 Introduction

When an industrialising country contemplates entry into a given industry, it confronts an environment already shaped by the history of that industry in developed countries and by long-established patterns of global trade. This chapter describes the historical development of the machine tool industry, the factors which have typically influenced its development, and the traditional trading patterns which have been established. The international trade of machine tools has changed considerably in the last decade with the expansion of Japan's exports. Why were Japanese machine tools such a success in the markets of other industrialised countries? Why couldn't existing domestic producers in these countries compete with these imported machines? And what are the implications of these changes on NIC and developing country manufacturers?

The overall structure and trade of the global CNC machine tool industry as it has developed from the 1970s reflects patterns which extend back to the nineteenth-century history of the machine tool industry. From a relatively early period the global machine tool industry has been characterised by a high degree of national specialisation and close links between each national industry and the manufacturing sectors that consume its products. Indeed, this chapter will show how global specialisation has emerged out of a variety of national producer-user links, and how in turn the significance of international trade in machine tools is a consequence of that specialisation. The organic patterns of interaction between machine tool manufacture and use have constituted an enormously consequential economic and technological environment for the industry. Close interactions between national machine tool industries and the general manufacturing sector have created and sustained the most important competitive environment for machine tool producers; they have imposed a formidable cost discipline; and they have provided both a

source and a direction of technological innovation. These relationships and their consequences apply no less to the CNC industry than they do to the conventional sector.

By contrast, relations between national machine tool industries and the military might be seen as an anomaly in this organic historical pattern. A number of machine tool industries, notably in the United States but also in other industrialised countries, have developed extremely close links with the military. Short-term profitability from supplying this sector has seemed to carry with it long-term risks. While the military influence was crucial for the early development of CNC machine tools, its legacy has been a continued direction of innovation towards a highly specialised sector and away from general manufacturing. Moreover, a military environment has loosened the competitive discipline which the civilian sector historically imposed upon machine tool firms. And the political unreliability of military consumers has exacerbated the endemic uncertainty constituted by normal manufacturing cycles. This has made already difficult investment decisions even harder to plan and take.

Given these historical patterns, the CNC industries of both Japan and Korea (discussed in Chapters 5-7) look like continuations of the organic relations between national machine tool industries and their domestic civilian users. The most influential links appear to be those between vehicle and machine tool producers. It is argued here and elsewhere that these links have not only directed innovation in the CNC industries of these countries but have exemplified the ways in which an indigenous machine tool sector can support its national manufacturing industries. Moreover, both the discipline and the direction imposed on national machine tool builders by these links have created, especially in the cases of Japan and Korea, industries which are well adapted to seize upon and exploit the opportunities offered by the historically shaped, specialised international market.

4.2 Features of the Machine Tool Industry

In most industrialised countries, the machine tool industry originated in other manufacturing industries because backward integration into machinery production was the only method of acquiring new machinery. The textile and armaments industries were both important early manufacturers of machine tools in Britain and America in the nineteenth century, and it was only in the middle of that century that firms specialising only in the manufacture of machine tools started to appear. As well as creating a market for machine tools, the textile and armaments industries also required different types of machines, or adaptations of existing ones, to manufacture new products. As different industries have grown in their importance, so new machine tool producers, and new types of machine tools, have emerged from these industries. These links have been a continuing feature of the development of the machine tool industry. Although defence is still a major influence on the machine tool industry, it is the vehicle industry that has been most important in the twentieth century. According to the historian R.S. Woodbury,

A volume should be written about machine tools and the automobile industry. In no industry has the technical development of tools been so crucial in all its aspects, and no industry has had such a great effect on the far smaller machine tool industry. Not only did the automobile industry after 1900 become the largest single customer of the machine tool industry, taking 25 to 30 percent of the output, but it actually increased its volume consistently (Quoted in Rolt, 1965: 218).

Other industries influential on the development of the machine tool industry in this century have been those manufacturing bicycles, sewing machines, and aeroplanes.

The machine tool industry is dependent on engineering industries for its market, and, consequently, rises and falls in engineering production have an accentuated effect on machine tool production. The profitability of machine tool firms is also affected by these swings in demand. During periods of high demand, the industry is more profitable than most manufacturing industries, but during down-swings it is far less

profitable (DiFilippo, 1986: 46). Because of the cyclical nature of the machine tool market, it is still fairly common for machine tools to be manufactured in conjunction with other engineering products or types of machinery. Multi-product firms are able to reduce their vulnerability to these swings in demand, reducing their production of machine tools during depressions and building it up with an economic upturn. For example, one machine tool firm visited in Taiwan still manufactured its original product, textile machinery, and altered the composition of its output depending on the state of the market for each type of machinery. Other manufacturers have diversified into new product areas. Cincinnati Milacron, the largest US machine tool producer, has considerably expanded its product range since the late 1940s, entering into the manufacture of chemicals used in metal cutting, plastic injection molding machinery, and silicon wafers (Cincinnati Milacron, 1984). Exporting machine tools is another method used by firms to try to reduce the effects of cyclical demand in the domestic market.

The largest rises and falls in demand for machine tools are associated with defence activity. During the build up of defence forces and in periods of war, the demand for machine tools expands very rapidly, and machinery producers have to quickly gear up their production to meet these demands. Between 1940 and 1943, the US machine tool industry manufactured more machine tools than had been produced in the four preceding decades (Cincinnati Milacron, 1984: 81). However, during an immediate post-war period, there is an extensive stock of machine tools no longer required for defence production. These machines are often released, at below market prices, onto the civilian market, and, consequently, the demand for new machines is further depressed. Production in the US industry continued to decline for five years after the end of World War II, and only recovered then because of demand from the Korean War (DiFilippo, 1986: 30-34).¹

The link with defence production means that governments often give the machine tool industry special protection or promotion. In the Korean case, an indigenous machine tool industry was promoted as an integral part of the expansion of heavy industries, in order to support the build

up of the defence sector. An advanced machine tool industry is also seen to be an integral part of a military-industrial complex which has to be continuously prepared for war. Such considerations also operated in the US, where high levels of protection were given to the domestic industry in 1986.

Although the industry is very technology- and skill-dependent, the scale of R&D effort and funding is remarkably low. Usually, only 1-2% of the value of sales is used for formal R&D, and a similar proportion is devoted to further product developments and improvements.² In the main, this research and development work is directly orientated towards meeting customer requirements. Only a few of the larger producers are involved in long-term research work. A probable cause of this low level of R&D investment is the cyclical nature of the industry. During periods of high demand, all of a firm's energy is put into the manufacture of machines to meet demand, while during low demand there are insufficient resources to invest in such work. Governments also have an important role in funding industrial R&D, and machine tool industries in many countries are given support either by direct funding of their own R&D efforts or through work undertaken by universities or research institutes. The orientation of this research work is obviously heavily influenced by government policy. DiFilippo compares government-funded R&D in the machine tool sector in the US, Japan, and West Germany. He documents the large machine tool projects funded for military purposes in the US, notably including the development of NC at MIT, and suggests that most of the technical sophistication of the US machine tool industry has resulted from military expenditure. In contrast, the Japanese and West German governments have helped civilian machine tool producers develop new machines by giving them grants and loans in high-risk development areas. The emphasis in these development projects was on machines for civilian use and not for defence purposes (DiFilippo, 1986: 48-61).

Technological developments by component suppliers to the machine tool industry have been an important factor in changes in machine tool design and manufacture. The introduction of high-speed steels in the US early in the twentieth century, followed by tungsten carbide tools

(originally developed in Germany in the 1920s) meant that machine tools had to be able to operate at high speeds in order for these tools to cut efficiently. The machines had to be rigid at higher speeds to ensure that there was no vibration in the tool tip, which would result in an uneven cut and rapid wear on the tool itself. Not only were newly designed machines about 75% heavier than previous models, but they incorporated new types of gears and bearings which had been originally developed for use in motor vehicles (Rolt, 1965: 227-29). Similarly, the application of electronics developments in machine tool control could only be effectively utilised with the introduction of other new components and alterations to the structure and configuration of the machine.

Typically, the historical pattern for national machine tool industries is one of many small and medium-sized companies and only a few, but important, large ones. In the US in 1977, of the 919 establishments where metal cutting machine tools were manufactured, only eight had more than 1000 employees, but these eight accounted for 28% of the total number of employees. In the same year, 822 establishments had fewer than 100 employees (NMTBA, 1985: 70). In West Germany, 22% of the total number employed in the machine tool industry work in the fifteen firms with over 1000 employees. The figures are similar for other European countries: in Italy, the UK, and France, firms with more than 1000 employees accounted for 10%, 22% and 25% of total industry employment respectively. Japan is the only country with a substantially different pattern: in that country over 50% of the total employed are in firms with over 1000 employees (Horn et al., 1985: 51). In general, the larger firms supply machinery to the major consumers of machine tools, such as the vehicle, defence and aeroplane industries. The smaller firms specialise in the manufacture of a very narrow range of products, which are utilised in a wide variety of markets. The narrow range of their output gives the producers advantages from economies of specialisation.

One analyst has claimed that the small size of machine tool firms and their high levels of specialisation have been a contributory factor to the slow rate of technical progress in the industry (Marx, 1979: 43). This author also suggested that there was a trend in the US industry

towards increased concentration as larger firms acquired smaller ones in order to expand their product range. One of Jacobsson's major conclusions was that significant economies of scale can be achieved in the manufacture of standardised CNC lathes through reductions in the price of components. He argued that in the long term firms need to manufacture about 1000 machines a year to be competitive, and that in order for European firms to be able to reach such levels of production, there should only be two firms operating in this product sector (Jacobsson, 1986: 98-100, 222-24). If his recommendations were to be followed, the industry would indeed become highly concentrated.

Not only do firms specialise in the production of certain types of machine tools, but certain countries have concentrated their expertise in specific sectors of the global machine tool industry. This specialisation has partly resulted from the national origins of machine tool industries. As noted earlier, it was common for a national industry to develop from engineering industries which required specific machine tool supplies. Consider, for example, the development in Switzerland in the early twentieth century of a jig borer by the Société G  n  voise (Rolt, 1965: 225-26). Initially, a pointing machine was developed at the request of watch-makers, which could be used to accurately mark the centres of holes to be drilled in watch parts. This machine was adapted so that it could also drill the holes. It was then enlarged so that it could be used in more general engineering work, but its accuracy to 1/10,000th of an inch was maintained. This machine is typical of the very high precision machinery manufactured by Swiss firms, much of which has been influenced by the requirements of the watch and clock industry.

This international specialisation has a further implication for the global industry, as it means that no country is now totally self-sufficient in the production of machine tools. In order to take advantage of their specialisation, most countries export machines in which they have either a technical or economic lead and import machines which they do not have the technical ability to produce or those which they can import more cheaply than they can manufacture. Over 40% of all machine tools produced are exported from their country of manufacture.

While these forms of specialisation have largely developed organically in industrialised nations, new entrants are faced with a situation in which firms and/or governments must take deliberate decisions to follow this general pattern, exporting machines in which they have some production advantage and importing machines in which they have none. They must, therefore, establish in which sectors of the international market they may have some potential advantage. For countries with very large domestic markets, exports may not be such an important consideration, as economies of scale and of specialisation in many areas of machine tool production can be achieved by supplying the local market. The USSR, the largest machine tool consumer in 1985, exports only a very low proportion of its production. (In 1985 it exported 6% of production and a high proportion of this went to Soviet-run factories in other Comecon countries.) However, this low level of exports does not indicate that the USSR is self-sufficient. In fact, in 1985 it imported over 30% of its domestic requirements. What it does indicate is that the USSR has not been able to find, and specialise in, any sector of the market in which it could expand its exports.

4.3 Global Machine Tool Production: A Change in Leadership

In the data for world machine tool production and trade prepared annually by American Machinist, a total of 36 countries were listed in 1985 as having a "significant" level of machine tool production. However, global production is concentrated in a very few countries. Since 1967, the biggest four machine tool producing countries in the world have been the US, West Germany, Japan, and the USSR. In 1985, their combined production accounted for 63% of total world output. Table 4.1 shows the production figures for these four countries, as well as the UK and Italy, for selected years between 1967 and 1985.

Table 4.1 Machine Tool Production By Leading Producer Nations
(in million US\$)

Country	1967	1971	1975	1977	1979	1981	1983	1985
US	1,900	1,100	2,451	2,635	4,059	5,111	2,106	2,575
FRG	800	1,550	2,403	2,440	4,006	3,953	3,194	3,123
Japan	450	950	1,060	1,602	2,893	4,798	3,541	5,270
USSR	900	1,150	1,984	2,201	2,903	2,932	3,077	3,015
Italy	200	450	873	878	1,354	1,513	1,037	1,056
UK	400	400	728	587	1,001	933	573	723
Total World Production	*	8,148	13,644	15,126	22,920	26,418	19,530	21,918

a. Figure unavailable.

Source: American Machinist, Various Issues

The most dramatic change during this period has been the rise of production levels in Japan. In 1967, Japan produced less than a quarter (by value) of the output of the US, then the largest producer in the world. By 1985, Japan was not only leading the world, manufacturing 24% of total world production, but was producing twice as many machine tools as the US. A similar change has taken place between two European

producer countries. In 1967, the UK industry produced twice as much (by value) as the Italian industry; by 1971, production levels were almost equal, and by 1985 the Italian industry was producing nearly 50% more than the UK. The total world production figures given in Table 4.1 also shows the susceptibility of global production of machine tools to swings in demand.

Table 4.2 Machine Tool Exports by Leading Producer Nations
(in million US\$)

Country	1975	1977	1979	1981	1983	1985
US	568	452	649	972	406	445
FRG	1,814	1,823	2,508	2,585	1,950	1,900
Japan	359	616	1,237	1,693	1,264	2,099
USSR	188	280	324	242	246	194
Italy	431	436	689	795	592	612
UK	363	300	473	537	318	336
Total World Exports	5,897	6,500	9,661	10,845	8,392	9,502
Total World Exports as a %age of World Production	43	43	42	41	43	43

Source: American Machinist, Various Issues

Table 4.2 indicates that, while the proportion of total machine tool production exported has changed little, the export shares of major exporting countries have altered significantly. In 1975, Japan accounted for 6% of machine tools sold on the world market, this proportion rapidly rising to 22% by 1985. While Japan has been increasing its share of the world market, the US share dropped from 10% to 5% during the same period. Again, Italy appears to have fared better than the UK; the UK's

share declined from 6% to 4% while Italy's dropped from 7% to 6%. West Germany, which had been the world's largest exporter of machine tools since the 1950s, also lost a large part of the world market, its 31% share of global exports in 1975 declining to 20% in 1985. West Germany is now second to Japan in the export league. The USSR remains one of the smaller exporters of machine tools with only a 2% to 4% share of world trade. However, the USSR imports a large proportion of the machine tools traded on the world market: in 1985 it took 14% of global exports (American Machinist, Feb. 1985: 69-73).

4.4 The Growth of CNC Production

In the last ten years, there have been two major and related changes in the world trade of machine tools: (i) there has been a rapid expansion in the output of controlled machine tools; and (ii) Japan has become the largest overall producing and trading nation, and increased its market share in many of the industrialised countries. In the production and trade of CNC machine tools, Japan's rise was even more dramatic. By 1981, every other CNC lathe purchased outside Japan was of Japanese manufacture (Jacobsson, 1984: 46). Japan's penetration of the US CNC market was particularly overwhelming. By 1985, three out of every five CNC machines bought in the US was manufactured in Japan, and in the case of machining centres this statistic was nearly three out of every four (see Table 4.4). How did Japan manage to capture such large sectors of this market? And why were the US producers unable to compete with Japanese imports? Japan's machine tool producers also increased their exports to Europe. Horn et al. show that CNC imports into the EEC from non-EEC countries increased by 123% between 1976 and 1983, while intra-EEC trade only rose by 23%. Of the imports from non-EEC countries, Japan's share rose from 12% in 1976 to 46% by 1983 (Horn et al., 1985: 76). Within the EEC, Italy managed to increase its output and maintain its export levels, while the UK declined in both output and exports. Why was the Italian industry able to cope with the changing international market, while the British industry was not? This section examines the CNC industries of each of these four countries, covering the important factors influencing their respective successes or failures in the transition from conventional to CNC production.³

4.4.1 CNC Production in Japan and the US

Table 4.3 shows production statistics of the Japanese and American NC/CNC industries for the years 1970 to 1983. Production of CNC machine tools in Japan grew rapidly between 1976 and 1980, increasing over eight times (by value) and nearly seven times (by units). During the same period, the American industry expanded just over two and a half times (by

both units and value). In terms of unit production, Japan overtook the US in 1977, and in terms of value in 1980.

Table 4.3 CNC Machine Tool Production by US and Japan

Year	<-----US Production----->			<-----Japan Production----->		
	Units	Value ^a	Average Unit Value ^b	Units	Value ^a	Average Unit Value ^b
1970	1,901	209	110	1,451	68	46
1971	1,238	153	124	1,379	71	51
1972	1,630	170	104	1,350	82	60
1973	2,865	272	95	2,765	174	63
1974	4,210	378	90	3,040	200	66
1975	4,136	505	122	2,188	134	61
1976	3,856	501	130	3,312	173	52
1977	4,482	497	110	5,436	300	55
1978	5,688	649	114	7,336	510	69
1979	7,925	1,015	128	14,317	937	65
1980	9,984	1,372	137	22,069	1,497	67
1981	8,945	1,467	164	25,926	1,968	76
1982	6,218	1,152	185	24,048	1,687	70
1983	4,737	680	143	26,398	1,795	67

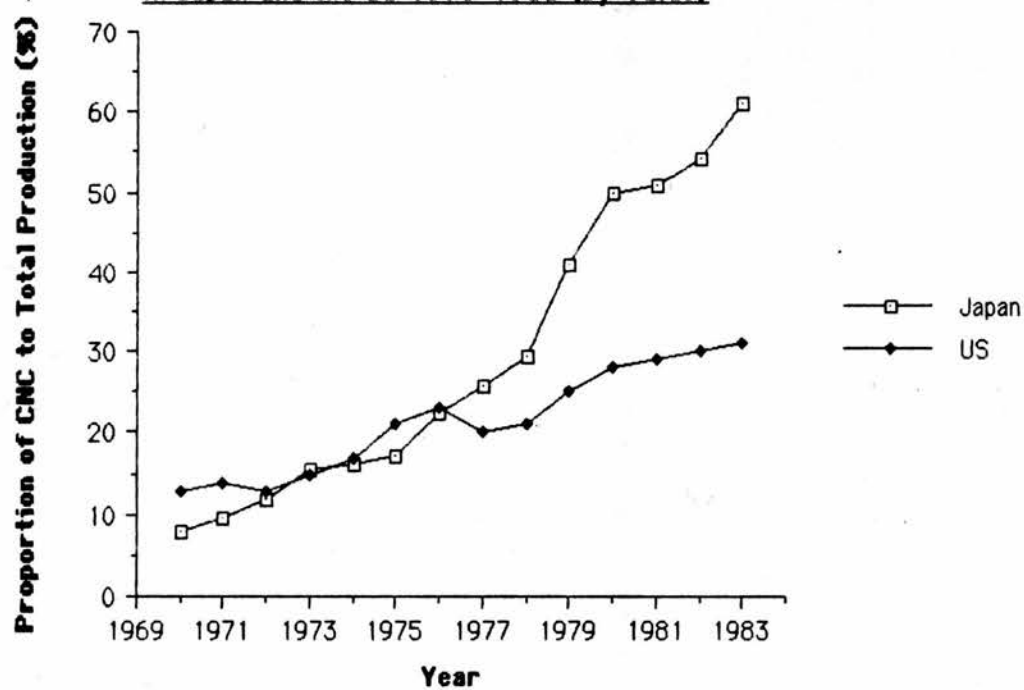
a. In million US\$.

b. In thousand US\$.

Source: NMTBA, 1986; 100, 202; Metalworking, Nov. 1982; 177.

One reason for the much faster growth of Japan's CNC machine tool output compared to that of the US derives from the more rapid rate of transition from conventional to CNC production by Japanese producers. The graph in Figure 4.1 shows the proportion of CNC to total production (by value) for Japan and the US between 1970 and 1983. From 1970 to 1975, the proportions of CNC production in both countries were similar. The CNC proportion of total machine tool production continued to rise in Japan, reaching 50% in 1980 and over 60% by 1983. The proportion in the US actually declined between 1976 and 1978, and has only risen slightly since, to approximately 30% in 1983.

Figure 4.1 Ratio of CNC to Total Machine Tool Production in Japan and the US 1970-1983 (by Value)



Sources: NMTBA, 1985: 100, 126, 194 - 98; Metalworking, Nov. 1982: 175.

The preceding chapter noted that NC machines were first successfully developed in the US by the defence industry, specifically for its needs, and an artificial, subsidised market was created to purchase the machines. The major subsequent NC and CNC developments in the US were also very closely related to defence requirements. The defence sector continued to be a very large consumer of NC/CNC machine tools through the 1960s and 1970s. DiFilippo (1986: 102) observes that throughout the 1970s the aerospace industry was a major consumer of CNC machinery, and, as an industry, had the largest percentage of controlled machine tools, using these machines principally for defence-related rather than civilian projects. In the mid-1960s, approximately 20% of machine tool demand in the US was generated by military spending. DiFilippo suggests that this may have declined slightly in the 1970s. However, using his own estimate of military-induced machine tool demand in 1978 of US\$741.5 million and the American Machinist figure of total US machine tool consumption of US\$3,159 for that year, military demand actually accounted for over 20% (DiFilippo, 1986: 107; American Machinist, Feb. 1980: 88). As US CNC production only accounts for a small proportion of total machine tool output, and as the major users are in the defence sector, the proportion of CNC output going to this sector was, without doubt, much higher than the figure for total machine tool output.

As the defence sector was the major NC/CNC consumer, most of the development of these types of machines in the 1960s and 1970s was designed for use by the military. Machines supplied under defence contracts were the most advanced available and their price was not a major obstacle. Many of the contracts from the defence industry, and new sophisticated consumers, the space agencies, were administered on a "cost-plus" basis. "Historical costing" was also used, which allowed for the price to be increased not only on engineering estimates but at a rate calculated from past increases in the project cost. These contracts encouraged firms supplying this sector to produce expensive and sophisticated machines and to neglect production costs. Melman (1983a: 61) suggests that the price of a US machine destined for export was a quarter that of a similar machine supplied to the Air Force with sophisticated controls.

The market for this kind of machine tool is very limited. In the US only defence and space contractors could afford the cost, as such machines were too expensive for the general metal working and vehicle industries. Furthermore, because of the strategic nature of the machine tools produced for the military, exports were often legally restricted. Under pressure from the machine tool industry, the US Department of Commerce did relax these restrictions in the early 1980s, but the export of machine tools for aircraft production, four- and five-axis CNC machines, high-precision CNC machines, and certain control units were still subject to restrictions even after 1983 ([US] National Academy of Engineering, 1983: 42).⁴ These links between the US CNC machine tool industry and the military have had very significant consequences. The industry has lost competitiveness and domestic and world market share to national producers whose development has been mainly shaped by links with civilian mass-production industries.

In Japan, NC machines were first produced in 1956, using US technical reports, by Fujitsu, a large electronics company. Two years later, Fujitsu developed a second NC machine in collaboration with Makino Milling Machine, a machine tool builder. The Tokyo Institute of Technology developed an NC lathe in 1957. Other firms which soon followed with their own NC machine tools included Ikegai and Hitachi Seiki. In 1957, the Mechanical Engineering Lab. of MITI (Ministry of International Trade and Industry) started a three-year project into the "Automatization of Machine Tool Operation" (Metalworking, July 1987: 22). Development of NC and CNC machines continued steadily, both in industry and in MITI's labs. In 1970, a total of 123 different Japanese NC machine tools were exhibited at the Japanese International Machine Tool Fair. While a large proportion of the development work on these machines was indigenous, Japanese producers also entered into licensing agreements to acquire NC technology. (The development of the Japanese machine tool industry and its acquisition of technological capabilities is documented in greater detail in Chapter 7.)

A main feature of the Japanese CNC industry in the 1970s was its concentration on the production of standardised low-cost machines. The

figures in Table 4.3 show that the average unit value of CNC machine tools manufactured in Japan has been approximately half that of those manufactured in the US. Watanabe, in his study (1983) of the growth of the Japanese machine tool industry in the late 1970s and early 1980s, argues that there are two factors that promoted the development of this type of low-cost production. Firstly, the users of machine tools in Japan are concentrated in general machinery, vehicles and electrical machinery manufacture. Of these, the largest single machine tool consumer is the vehicle industry and its many components suppliers. The links between these two industries have been very close and some of the major machine tool producers are either part of vehicle groups or make machinery entirely for the vehicle industry. Post-War Japan lacks a substantial aircraft industry and has only a very limited defence sector, so the Japanese machine tool industry is not orientated towards these markets. Secondly, small and medium-sized firms, which are used as sub-contractors to the large industries, provide a large market for standard general purpose machine tools in Japan. In order to cater for this market, the machine tools produced, whether conventional or CNC, have to be fairly low-cost, and it was for this market that low-cost CNC machines were designed. With the great demand for these machines, the machine tool builders have been able to make price reductions by producing in batches that are large enough to justify using mass-production techniques.

It was these standard, low-cost CNC machines which led Japan's export expansion and which enabled Japanese producers to rapidly build up a large market share in the US. Japanese producers supplied the same types of users in the US as they did in Japan, i.e., the vehicle industry and general metal working firms. But why did the US machine tool industry concentrate on the requirements of the defence sector and not develop machines for other sectors of the market?

The importance of a developmental link between the vehicle and the machine tool industries had been recognised in the US as early as 1963. A Senate Staff Report then concluded:

The automotive manufacturers and the [machine] tool and die industry should establish a close working liaison regarding ... research in the use of new computerized numerical control equipment. Only through a close working relationship and good communications within these two industries can long-term satisfactory results be accomplished (Quoted in Marx, 1979: 45).

In fact, no such close liaison was ever achieved. In 1979, T.G. Marx, an economist with General Motors, claimed that the vehicle producers had taken over the role of technical leaders in the development of CNC machinery for their own use and had entered collaborative development projects with machine tool firms (1979: 45). In spite of these signs in the late 1970s that the US vehicle industry was getting closer to the machine tool industry, by 1985 GM was again critically assessing this relationship. GM considered that a major factor in the low level of R&D in the US machine tool industry was its own method of buying machinery. Traditionally, GM asked firms to submit tenders, which might themselves be expensive to prepare, and the final decision was made principally on a cost basis. Under these conditions, the machine tool firms always chose the safe option and did not undertake any significant development work. Following this report, GM started to establish closer links with a few machine tool builders who were prepared to collaborate closely with them and with each other. It should be noted that, unlike many of the Japanese vehicle producers, GM does not have a machine tool building subsidiary, although it did establish a joint venture with a Japanese company, Fanuc, to manufacture robots.

Even without close ties to the vehicle sector, there were also serious problems within the machine tool industry. Melman (1983a: 61-64) suggests that a major failing of the US industry was its management. US machine tool firms not only concentrated on the production of highly profitable machines for the defence industry, but they did not invest in their own production equipment. Large-scale military projects tend to exaggerate normal industrial cycles of demand, and long-term investment in plant was avoided since it appeared to be an expensive overhead during periods of low demand.⁵ Thus, the machine tool industry itself was not a major CNC user.⁶ Firms continued to make a very wide range of machinery,

and, therefore, individual firms could not apply mass-production techniques. Melman also notes that while the very sophisticated end of the market was becoming more expensive and profitable for the producers, the lower end of the industry was also experiencing cost increases. In the US, the average unit-cost rose 85% between 1971 and 1978, during which time machine tool prices in Japan only rose 51%, even though Japanese wage rates were rising much faster than those in the US.

The general metal working industry in the US did not immediately respond by importing machine tools; it simply relied on its existing stock. Following the oil crisis of the early 1970s, the US car industry started to re-tool its production plants in order to produce smaller, more fuel-efficient cars. Unable to buy domestically-produced standard machine tools, it, like many other metal working sectors, imported new machines from Japan. A major problem with US machine tools was their very long delivery time. In the delivery of machining centres, US producers took between twelve and eighteen months, while Japanese producers could deliver within three (DiFilippo, 1986: 71). Furthermore, the lead-time taken by US producers to develop new products was also much longer than that of their foreign competitors, which meant that they could not quickly bring out new products or copies of Japanese machines. The figures in Table 4.4 show how Japanese CNC machine tool producers have continued to increase their share of the US market from 1980 to 1985.

Table 4.4 Japan's Shares of US CNC Machine Tool Markets

Machine Tool Sector		1980	1981	1982	1983	1984	1985
Japan's %age Share of Total US CNC Market	} by value	16	24	25	28	36	41
	} by quantity	25	38	41	43	50	58
Japan's %age Share of Total US CNC Lathe Market	} by value	23	35	35	29	42	46
	} by quantity	40	56	54	51	60	65
Japan's %age Share of Total US Machining Centre Market	} by value	17	28	33	46	50	55
	} by quantity	30	49	56	68	66	71

Source: Metalworking, May 1987: 21.

The high levels of penetration in some export markets have led to restrictions on the quantities of Japanese machines that can be imported. In late 1986, Japan entered into a Voluntary Restraint Agreement with the US, under the terms of which the Japanese industry agreed to reduce its share of the US domestic market for CNC lathes and machining centres to 1981 levels. The market share for Japanese conventional machines was limited to its 1985 share. The total effect of these measures was anticipated to reduce Japanese sales in the US by US\$795 million over the following five years (Wall Street Journal, 17 Dec. 1986: 4). The increased protection of the US market does not appear to have helped the domestic machine tool industry and may indeed have been a contributory factor to the reduction in consumption. In 1987, although global machine tool production was 8% greater than in 1986, US production declined by 11% and US consumption declined by 13% (American Machinist, Feb. 1988: 62-63).

Many Japanese machine tool producers have commenced offshore production, and this has enabled them to by-pass voluntary restraint agreements and to avoid rising production costs in Japan, following the appreciation of the yen. Yamazaki began production in the US as early as 1974 at a plant designed to produce 120 machines a month. Hitachi Seiki has also produced CNC lathes in the US since 1981 and became a member of the American machine tool manufacturers association (NMTBA). In 1981, Makino, following a different strategy, bought LeBlond, one of the oldest US firms which specialised in lathe production, reduced the workforce from about 1000 to 500, and installed Japanese managers. Makino renamed the new company LeBlond Makino, in order to "retain the image of being an 'American builder' and to allow the local firms to make full use of that image in sales" (Metalworking, May 1985: 34). Makino also acquired a 50% share of a German lathe producer and established a subsidiary of LeBlond Makino in Singapore. Other Japanese producers have set up close management and production links with established indigenous producers in various countries and have entered licensing agreements for their products to be manufactured and sold overseas.⁷ This means that in the 1980s Japan was not only the leading producer of CNC machines but also the principal CNC machine tool technology supplier in the world.

Moreover, Japan has also become a leader in the development of Flexible Manufacturing Systems. One of the main features of FMS production is that the design stage requires intense collaboration between designers and users. This means that the producer and user must, for all practical purposes, be based in the same country in order to liaise on the design, so the export of an FMS as a complete system is virtually impossible. However, with the expansion of Japanese machine tool firms into other countries, they are now able to supply these systems directly to various domestic markets. Indeed, this was one of Makino's explicit aims in acquiring its American and German firms. Makino's main specialisation was in the production of milling machines and machining centres, and, by taking over lathe producers, these links enabled the company to expand quickly into all types of machine production. And, as the company now has a strong local production and engineering base in the US and Europe, it is able to sell systems in these markets.

Not only did the US machine tool industry lose its technical and market lead to Japan, but its controls producers were similarly eclipsed by their Japanese counterparts. Control unit production is extremely specialised; it has only one consumer - the machine tool industry - and, within that industry, it sells only to the most technically advanced firms. Firms manufacturing control units may be divided into two types: (i) machine tool manufacturers making control units for their own output, and (ii) electronics firms producing controls to sell to machine tool producers. By far the largest share of the control unit market is taken by the second type. The largest controls manufacturer is the Japanese company, Fanuc, and in 1985 it claimed to have 75% of the Japanese market and 50% of the world market (The Economist, 29 June 1985: 64). Other specialist controls producers include General Electric, Allen Bradley, Olivetti, Siemens, and Philips.

Japan's domination in this sector is, therefore, principally a result of the success of one company. Fanuc originated in the mid-1950s as a research group set up within the electronics conglomerate Fujitsu to look at the development of controls. The group was led by a mechanical

engineer, Dr. Seiueemon Inaba, and its main source of information was a report from the MIT Servomechanisms Lab. which was sent to them by a Japanese professor who had been working in the US. Inaba later acknowledged that "the 50-page microfilmed report was excellent. In fact for us it was a sort of bible on NC" (Metalworking, Nov. 1982: 192). The first controls they developed used parametrons as the electrical control element rather than the vacuum tubes which had been used in the MIT unit.* Parametrons, however, proved to be too unstable in use and the circuits too complicated, and so were soon replaced by vacuum tubes. Early development projects were undertaken in collaboration with machine tool builders. The first machines that were used commercially were developed with the machine tool builder, Hitachi Seiki, and were financed by Mitsubishi Heavy Industries' Nagoya Aircraft Factory, in which they were used. The control system contained about 100 vacuum tubes, of which at least one burnt out each day and stopped the operation of the machine. In order for the machine to be operable, a Fujitsu employee (with a large supply of vacuum tubes) continuously tended the system for the first six months of its operation (Metalworking, Nov. 1982: 195). Unlike the MIT system, which had a closed loop, Inaba initially used an open loop control system, which was technically less sophisticated but was more reliable.

As new microelectronics components were developed, they were rapidly incorporated into new control units and made commercially viable. In 1959, a fully transistorised NC unit was introduced by the group. In the early 1970s, Fanuc, still in collaboration with Fujitsu, developed a large-scale integrated chip for use in control units and these units included microprocessor control (Vogel, 1985: 82). In the mid-1970s, the firm also started to manufacture the other large electrical component used in CNC machines, servo-motors. Fanuc has also entered other sectors of the machinery and automated equipment market, manufacturing robots, EDMs, and plastic injection molding machinery. However, it never considered entering machine tool production itself, as it wanted to retain as large a market share as possible and not become a potential competitor to its users. Fanuc continued to maintain close links with machine tool

builders by organising regular meetings with them to discuss technical problems and developments (Watanabe, 1983: 37).

The NC group at Fujitsu continued to develop control systems and commenced trading under the name Fujitsu Fanuc (Fujitsu Automatic Numerical Control). The group made a loss on its production and development of control units for the first nine years of operation. In 1972, Fanuc became an independent company. However, Fujitsu still owns 42% of Fanuc, and they may still be regarded as part of the same *keiretsu*. Fanuc also closely collaborated with Siemens from the mid-1960s, and they jointly established a new company in the US, General Numeric Corporation, to supply that market.

The major producer of controls in the US has always been General Electric, which had a long involvement with NC as an early user of NC machine tools and as a producer of control units. In the late 1950s and early 1960s, General Electric was the control unit market leader, and had an appreciable share of the world market. Having developed its Mark Century range as a market leader, it continued to sell these hard-wired systems and failed to keep up with rapidly developing microelectronics technology by incorporating solid-state components in its units. Eventually, the pressure from Japanese competition, mainly from Fanuc, forced General Electric to reconsider its product and in 1979 it did finally introduce a solid-state control unit. The case of Allen-Bradley, another US controls producer, was similar. In the late 1970s, this company launched a new hard-wired control unit which was a total failure on the market. The firm then developed a solid-state controller and commenced marketing this in 1980, although with only marginal success.

In 1983, General Electric set up a Factory Automation Group. This group was to develop a new control unit which was to be more elaborate, with a greater number of features, but it was also to be of a simple design. The proposed system would be able to simulate the motion of the machine on a display screen while it was being programmed. A number of computer and software specialists were employed in the group, but there was a remarkable lack of knowledge of either machine tools or the cutting

process. In use, the new control unit was unsatisfactory, largely because of software problems. The result of this exercise was a further drop of 30% in the sales of General Electric's controls both in the US and on the world market. General Electric had similar problems in the development of other automation areas, including robotics and CAD (Petre, 1985). In 1986, it entered into an agreement with Fanuc to establish a joint-venture company (General Electric Fanuc). Under this agreement, Fanuc's CNC controls are assembled in the US, and are sold through General Electric's already established sales and service networks (Metalworking, July 1987: 31).

Thus, in the manufacture of both CNC machine tools and control units, US firms lost a large share of their domestic market to Japanese producers because they did not develop products which were acceptable on the general metal working market. One factor in their product developments was a desire for short-term profitability. Machine tool firms concentrated on the highly profitable defence sector and did not invest in their own manufacturing activities, in case such investment was followed by a depression which would result in large losses. In the controls industry, once a satisfactory product had been developed, firms continued to reap large profits on these but did not invest in new technological developments. In contrast, Japanese producers concentrated on the manufacture of lower-cost, standardised machinery. These were developed in collaboration with the vehicle industry, where the market for them grew very rapidly. In controls production, Fanuc continuously applied new technology as soon as it was available, and worked very closely with the machine tool industry in these developments.

4.4.2 Japanese Challenge - European Responses

The US market was not alone in being massively infiltrated by low-cost standardised CNC machine tools from Japan; Europe also experienced great increases in imports from Japan and a consequent decline in indigenous industries. This section assesses the situation in two European countries, the United Kingdom and Italy, following the increasing use of CNC machines and Japan's entry into their markets.

(1) United Kingdom Machine Tool Production

Floud shows that the British machine tool industry lost its early world lead in the production of machine tools to the US and Germany in the late nineteenth century (1975: 68-74). By the 1960s, most of the machine tools produced in the UK were of low unit value and basic design, while imports consisted principally of high-performance and high-precision advanced machine tools. The majority of exported machines went to developing and Commonwealth countries. A major problem in the UK industry was the lack of skilled labour. Skill shortages were a general problem in most sectors of British industry, but the problem was accentuated in the machine tool industry because of its higher than average skill intensity. As in the US, the UK aircraft industry was an important purchaser of NC machines in the early 1960s. However, with the cancellation of the TSR2 and other aircraft projects in 1964-65, this market rapidly contracted and the commercial market only grew slowly.⁹

Early development in NC technology in the UK was undertaken by Ferranti in the early 1950s. This firm was manufacturing wave guides used in radar systems. Production of these guides involved the accurate machining of a large number of small channels. In 1955, Ferranti engineers retro-fitted a milling machine with a control unit developed in-house. In 1956, Ferranti's system was even judged to be more advanced than those available in America by the US Air Force which was then starting to place batch contracts for NC machinery. These contracts, however, were intended to encourage the development of US industry, and the Air Force was obliged to buy from the domestic market (Layton et al.,

1972: 180). Ferranti continued to develop control systems, and sold several to other British companies including Lucas, BAC, and Hawker Siddeley. A joint project with British Oxygen Co. commenced in 1960 to develop a controlled flame cutter, and several of these systems were sold to shipbuilders. By 1967, three British companies - Elliot, Ferranti, and English Electric - had a combined 13% share of the world market for industrial process controls, Ferranti's contribution being in machine tool control (Shanks, 1967: 166).

The controls developed by Ferranti were aimed at the sophisticated end of the market and the company continued to invest heavily in the development of this product. In the late 1960s, the firm considered that success in this sector required R&D expenditure of at least £500,000. At this time, the whole of the UK market was worth approximately £4 million and Ferranti's turnover was less than £3 million (Layton et al., 1972: 182). Because of its very high expenditure on R&D, Ferranti was unable to invest sufficiently in either a marketing or a service network. In an attempt to increase its product range and its European market share, in 1969 Ferranti approached a West German company, Grundig, with the intention of forming a joint venture. In contrast to Ferranti's sophisticated controls, Grundig had developed a simpler system. Grundig, however, was not interested in forming a new company and the project was dropped. Later in the same year, the Industrial Reorganisation Corporation, a government-sponsored body, decided that machine tool controls production in the UK should be rationalised. In this plan, the interests of three firms (Ferranti, Plessey, and Airmec) were combined in one single group under the general administration of Plessey, and Ferranti agreed not to re-enter the sector in the next ten years. In fact, Ferranti never took up machine tool controls production again, although it has continued developments in drawing office automation and it manufactures computer-controlled coordinate measuring machines.

Plessey's original controls development work was in collaboration with Alfred Herbert, a large machine tool builder. In this project, a control unit for a jig borer, which Herbert manufactured under licence, was produced. Plessey continued to specialise in the production of

high-accuracy controls for use on jig borers and had a large share of this particular market sector. To diversify its product range, Plessey entered into licensing agreements, firstly with Bendix and then with Bunker-Ramo, both American companies. In the agreement with Bendix, Plessey's markets were strictly limited, and the Bunker-Ramo control was very sophisticated. Thus, Plessey was unable to expand its markets and its products were still concentrated at the top end. The third firm in the newly formed group, Airmec, was different from the others as it was a small company specialising in electronics and laboratory instruments, and its major project developments had been in small and simple control units (Layton et al., 1972: 177-84).

The merger of the three controls producers should have given the newly formed group benefits from a wider product range and a better sales and servicing network, provided by access to the Plessey International Organisation which had an established network in both Europe and the US. Layton et al. considered that:

Of the three British companies .. the company [Plessey] which has absorbed the others has been the company with the keenest eye for profit, the largest effort in marketing and servicing and the most rigorous and disciplined company-wide system of financial control (1972: 185).

This "keen eye" for profit and a lack of commitment to R&D in the product proved to be fatal for the newly formed group. The market was still neither large nor particularly profitable. Only eighteen months after its formation, the newly created NC division within Plessey was divided up and sold to Bunker-Ramo and SIA, a software consultancy, since it was not regarded as profitable.

A similar merger, with an almost identical result, took place in the machine tool industry itself. In an attempt to improve efficiency by increasing the size of production runs, Alfred Herbert, the largest UK producer, took over several other British machine tool companies, with the support and encouragement of the government in the 1960s.¹⁰ The overall aim was to try to obtain economies of scale. Moreover, grants were given by the government in 1970 to establish a joint venture between Alfred

Herbert and Ingersoll, an American company. The new venture was not a success; its products were too conservative and the existing management had difficulty controlling the enlarged company. After several further injections of cash into the company, totalling £45 million by 1979, it was finally divided into four parts (Daly and Jones, 1980: 58). The new companies never recovered, but some of the remaining fragments were absorbed into a British engineering group, Tube Investments, in the early 1980s. This new company now has fairly close links with its close neighbour, the car-maker Jaguar.

Subsequent government intervention in the machine tool industry has been in the form of grants and subsidies for the development and acquisition of new technology machines by British firms. In the 1970s, subsidies were given for new machine tool developments, and in the 1970s and early 1980s grants towards the purchase of new, advanced machine tools were given to general manufacturing firms. These latter grants were made to firms whether they purchased indigenously produced or imported machines. Horn et al. note that nearly half of the grants awarded in the early 1980s had gone on foreign machinery, thus doing little to promote domestic machinery production (1985: 65). While the British industry was having its domestic problems, it also found that it was losing its export markets. Increasing competition came from Japan and, in the conventional low-cost machine tool market (the UK's traditional export sector), from the NICs which had much lower production costs due to lower wages. The Machine Tool Trades Association, the British association of machine tool producers, appears to have had little or no effect on the promotion of indigenous production. One reason for this is that membership is open to importers and traders of machine tools as well as to domestic producers.

On the domestic market in the early 1980s, small machining centres were becoming increasingly important, yet domestic production of these machines was very limited while imports from Japan were rising. UK producers were left with three options: (i) develop their own machining centres and arrive in the market late, (ii) ignore the new growing market and try to expand in other areas, or (iii) to make the machines

immediately under licence, thus building up experience in their production and gaining a share in the market but taking lower profits. In response, five of the larger firms, including one US subsidiary based in the UK, negotiated agreements with Japanese companies. These agreements not only included the transfer of machine tool designs, but in the early stages included the supply of many components. For example, Bridgeport entered into an agreement with Yasuda which initially involved assembling kits from the Japanese firm, but within a year it was producing all the large machine parts except the control unit (Rodger, 1984).

While many of the British firms have entered into technical agreements with Japanese companies for the production of CNC machines and robots, in 1987 one large Japanese firm, Yamazaki, established a production plant in the UK. This new plant was built with the aid of £5.2 million from various government assistance grants. Initial production was set at 35 machines per month, to be manufactured from kits supplied by the Japanese parent. In the long term, the machines produced will have an EEC content of 60% and production will increase to 100 machines per month.¹¹ This would double the existing output of CNC machines in the UK; however, 80% of output is intended for export, some of which will go to Japan (Garnett, 1987d).

Italian Machine Tool Production

The Italian machine tool industry manufactures highly automated machines and systems for the vehicle and aerospace industries which form an important component of its domestic market. The industry also caters for large numbers of small metal working work-shops, by producing a wide range of general purpose machine tools. It is traditionally structured, with a large number of small firms and only a few large companies. Indeed, its average firm size of 150 employees is the lowest in Europe (Jones, 1983: 199).

The main vehicle of support by the government has been through the Sabatini Law, which enabled the Italian machine tool producers association (UCIMU) to provide a technical advisory service to producers and credit

packages to consumers. These provisions have proved so successful that over 80% of sales in Italy are covered by this arrangement. Furthermore, as the credit offered is only available for indigenously manufactured machinery, the Italian domestic industry, unlike the situation in the UK, has been the only beneficiary. Additional provisions operated through UCIMU allow domestic producers to obtain a credit subsidy on their exports (Jones, 1983: 199-200). UCIMU was also important in the development and promotion of basic, low-cost, machining centres in small machine tool firms, and a large proportion of the recent expansion of the Italian machine tool industry has been based on these machines (Horn et al., 1985: 63). Finally, to encourage exports to developing countries, UCIMU operates a company which establishes vocational training schools, thus supplying the training required with new investment in these countries (American Machinist, Jan. 1981: 84-85).

Olivetti is the largest Italian controls manufacturer. It is linked to Allen-Bradley, an American controls producer, and manufactures and markets controls in Europe for this company. Unusually for a controls producer, it is also a machine tool manufacturer. It established its own subsidiaries to manufacture machining centres and robots, and in 1981 it acquired a large Italian lathe manufacturer. These internal machine tool producers benefit from their links with Olivetti because they get control units at a lower price compared to other Italian manufacturers and have more access to and influence on the development of controls software (Jacobsson, 1986: 86). Production capabilities in the mechanical hardware, as well as in the electrical hard- and software, gives Olivetti the capability to install complete factory automation systems.

A major change in the Italian machine tool industry in the late 1970s was the emergence of a large machine tool and manufacturing equipment builder, Comau, under the auspices of the Italian vehicle producer Fiat. This new subsidiary was created out of three previously established Italian machinery builders. In the early 1980s, Comau accounted for 16% of the total Italian machine tool industry workforce (Jones, 1983: 199). Comau produces advanced manufacturing equipment, including robots and machine tools, and the majority of its output is

utilised in vehicle production. In an attempt to expand into the US market, the firm established a joint venture with Bendix in 1983, but this was abandoned in the following year when Bendix was taken over. The short-lived link in the US market did, however, help this firm establish a base in that market which it has subsequently been able to exploit (Horn et al., 1985: 64). In 1987, Comau's US subsidiary was the main supplier of assembly machinery for the manufacture of cylinder heads at General Motors. Interestingly, General Motors recently acquired a 20% holding in this US subsidiary, representing a departure from its previously distant relationship with machinery builders (Lane, 1987).

A major factor in the success of the Italian machine tool industry has been the role of UCIMU. Compared to other national machine tool associations, UCIMU is very different in that it not only undertakes general assistance functions, such as marketing information, export promotion and government lobbying, but also centrally provides many commercial functions to its member firms, particularly in the financial field and in technical developments. By centralising these functions, small machine tool builders have been able to achieve cost reductions on their manufacture of standardised CNC machinery and compete more effectively with Japanese imports. Additionally, the restriction of UCIMU credit to domestically manufactured equipment protected the Italian market. The UK industry tried to achieve economies by creating a large production unit, but management was unable to operate this new firm efficiently and it failed. Moreover, the provision of grants by the UK government for investment in new equipment did little to encourage the purchase of indigenously produced equipment.

4.5 The Status of the Newly Industrialising and Developing Countries

American Machinist's 1985 production figures included the output of nine newly industrialising and developing countries. Combined, these countries only accounted for a small proportion (6%) of total world production. Table 4.5 shows production figures for these nine countries for years between 1977 and 1985, and import and export statistics for the same years are given in Table 4.6. 4% of world exports originated in these countries in 1985, while they imported 9% of the machines traded on the world market. Taiwan is the largest exporter and, indeed, exported more by value than all the other eight countries together. The largest proportion of Taiwan's exports went to industrialised countries, mainly to the US but also to Europe. Similarly, in 1985, most of Korea's exports also went to the US. Most of the machines exported by the remaining countries go to other developing countries or to specific trading partners. India, for example, exports many of its machines through barter agreements with the USSR: in 1983 over 50% of Indian machine tool exports went to the Soviet Union under such arrangements (IMTBA, 1985: 14).

The largest developing country producer is the People's Republic of China. Although China's exports of machine tools have increased over the years covered, only a small proportion (less than 10%) is now exported. China imports about a quarter of its annual machine tool consumption. India is the second largest developing country producer, and its trading patterns are very similar to those of China. India's exports account for less than 10% of production and imports for nearly 40% of domestic consumption. India's and China's levels of production, in relation to other industrialising and developing countries, as well as their trading patterns, have remained much the same over this period.

Of the four Asian NICs, Taiwan and Korea are the most significant producers. In 1977, their machine tool industries were approximately the same size. In the late 1970s and early 1980s, both their industries expanded rapidly. While Korea's growth has been fairly steady, that of Taiwan has been more variable. Taiwan's growth was particularly rapid up to 1981, but then declined in 1983 with the slump in world industry

before increasing again. In 1985, Korea's machine tool output was about two-thirds that of Taiwan. Taiwan's exports have also grown rapidly and in 1985 80% of its machine tool output was exported. Korea, in comparison, only exports a very small proportion of its production, less than 15% in 1985. Taiwan's machine tool imports have consistently accounted for a large proportion of domestic consumption (68% in 1985). By contrast, Korea's machine tool demand has risen and fallen dramatically in response to changes in indigenous manufacturing investment. In peak years, a high proportion of this demand is met by imports (e.g., in 1979 and 1981, 73% and 70% of consumption was imported respectively). Overall, Korea is a larger consumer of machine tools than Taiwan, and Chapters 5-7 offer detailed analyses of their national industries.

Table 4.5 Machine Tool Production in Industrialising and Developing Countries
(in million US\$)

Country	1977	1979	1981	1983	1985
China	355	420	440	475	453
India	90	127	209	217	283
Taiwan	58	198	249	205	262
South Korea	57	164	178	119	184
Singapore	6	26	44	15	34
Hong Kong	*	*	13	5	4
Brazil	283	387	305	98	153
Argentina	60	62	35	28	7
Mexico	6	16	24	13	25
Total World Production	15,126	22,920	26,418	19,530	21,918

a. Not included in American Machinist figures for these years.

Source: American Machinist, Various Issues.

Table 4.6 Machine Tool Trade by Industrialising and Developing Countries
(in million US\$)

Country	1977		1979		1981		1983		1985	
	I	E	I	E	I	E	I	E	I	E
China	50	10	60	28	125	30	150	35	137	34
India	55	21	46	20	104	23	149	23	162	20
Taiwan	36	50	91	144	99	183	109	132	112	209
Korea	130	2	398	15	325	32	21	36	150	25
Singapore	33	12	84	24	114	27	113	46	143	84
Hong Kong	-	-	-	-	4	4	2	1	5	1
Mexico	80	3	85	2	450	4	110	2	155	1
Argentina	57	15	75	12	70	20	24	14	8	1
Brazil	170	11	132	28	124	74	44	24	22	22
Total World Exports	6,500		9,661		10,845		8,392		9,502	
I = Imports, E = Exports										
a. Not included in <u>American Machinist</u> figures for these years.										

Source: American Machinist, Various issues.

The other two Asian NICs, Singapore and Hong Kong, are relatively minor producers. Hong Kong was a very small producer when it first appeared in American Machinist's figures in 1981, and by 1985 its output had dropped dramatically. In 1985, it was the smallest producer country considered, and its production levels had continuously declined. The major factor in this decline was the increasing availability of very cheap Chinese machinery with which the Hong Kong manufacturers could not compete. Singapore's machine tool industry is different from that of the other countries covered as most production is not undertaken by local companies but through foreign-owned firms. Three large foreign machine tool manufacturers (Bridgeport, LeBlond-Makino, and Okamoto) have established assembly plants in Singapore. (A fourth firm, Traub of West Germany, also established a plant there in the late 1970s but closed it

down in 1983, explaining some of the variation in production figures.) There is a notable anomaly in Singapore's production and export statistics: in several years it apparently exported more than it produced, a situation explained by Singapore's role in entrepôt trading: many machine tools destined for other Southeast Asian countries are routed through Singapore, in order to avoid import tariffs imposed by these countries on goods from outside the region. A significant proportion of Singapore's imports are, therefore, destined for re-export and not for domestic use.

The only large producer country in Latin America is Brazil; Argentina and Mexico both have much smaller industries. Production levels in these three countries peaked between 1979 and 1981, and have subsequently fallen. Brazil and Mexico have since regained some of their lost production, but Argentina's industry has continued to decline. A high proportion of the machinery exported by these countries remains within Latin America. Imports from outside the region have been restricted in all of the countries. And, because of difficulties in importing machinery into Mexico, a large number of machines have been smuggled over the US border (American Machinist, Feb. 1986: 92). In the mid-1980s, import restrictions in all Latin American countries were relaxed to some extent.

4.6 CNC Production Strategies for the NICs

Although the output of firms in NICs and developing countries is very small in relation to total global production, many producers in these countries are now well established in the manufacture and export of conventional machines. Indeed, their successful production and export of machines in this sector was a contributory factor in the decline of exports of basic low-cost machine tools from the UK industry, which could not compete with these lower wage countries. As already shown in this chapter CNC machines are becoming an increasingly important part of the world market and, in addition, on the domestic markets of the NICs and developing countries, while the market for conventional machine tools is declining. Moreover, countries like Korea and Taiwan are now facing competition in conventional manufacture from producers in lower wage countries, such as China and India, which can undercut them in export markets.

For these reasons, some NICs, especially Korea and Taiwan, have seen the necessity of entering the CNC sector. Several of China's machine tool firms have negotiated foreign technology agreements with West German, Japanese, US, and UK firms to manufacture machine tools, including, but not restricted to, the production of CNC machines, FMSs, control units, and robots (Metalworking, Nov. 1986: 136-41). India has begun some CNC production and two companies have entered licensing agreements with UK firms to manufacture CNC machines. Jacobsson (1986: Ch. 6) describes the development of a CNC lathe by an Argentine producer in the early 1980s. The largest NIC CNC producers are Taiwan and Korea, and both these countries have also exported CNC machines to industrialised countries. In 1985, approximately a quarter (by value) of Korea's output and 15% of Taiwan's was in CNC machines. However, their CNC output is still very small in comparison to industrialised countries: in 1985, Japan's CNC output was over 100 times that of Korea and almost 90 times that of Taiwan (Metalworking, Nov. 1986: 146, 154; *ibid.*, July 1987: 25). Which sectors of this new market can such countries contemplate entering? and in which product areas can they become internationally competitive?

Production strategies for NIC firms in the manufacture of CNC machine tools are influenced by many of the internal and external factors treated in Chapter 2. The main internal factor limiting entry into new product areas is the pool of skills a firm can mobilise. A crucial consideration is the technology of the product itself and the difficulties in building up the new capabilities required to design and manufacture it. Given its skill base and its opportunities for acquiring new skills, which types of CNC machines can a NIC firm reasonably aspire to manufacture? The market for these machines must also be analysed. Who will buy the finished machines? Can they compete with those manufactured by other domestic or foreign producers? Decisions about these questions will be influenced by the domestic user market, the existence of potential competitive advantages, the support available from components suppliers, the policy of the government, and the mechanisms by which government implements policy.

The majority of machine tool manufacturing in NICs is still concentrated in standardised, low-value conventional machinery, and it is from this skill base that firms enter CNC production. In the manufacture of CNC machines, the highly specialised and sophisticated sector is not a viable entry point for NIC producers; they have neither the skills nor the experience, and these are both difficult to acquire. It would also be very difficult to export these machines, as firms need first to build up some "credibility" on the global machine tool market. At the standardised end of the CNC market, technological requirements are much lower and it is feasible for NIC manufacturers to enter this sector. Nevertheless, firms entering production at this level still need to acquire new technological capabilities. In particular, firms have to be able to adapt and modify designs in order to follow the technological frontier. And, if they are to develop their own new models, and not remain as technology followers, requirements for skilled core designers are considerable.

However, it is in this part of the market that price competition, especially from Japanese producers, is an important factor. Furthermore, in this sector the contribution of bought-in components to the final machine tool price is very high, often over 50%, with a large part of this

being made up by the control unit. In the manufacture of these machines, labour only accounts for a small part of total cost, so that lower wage rates, the traditional source of NIC competitive advantage, can only marginally contribute to the competitiveness of NIC producers. Indeed, these firms are often at a distinct disadvantage to large producers in industrialised countries which are able to benefit from economies of scale and from significant component price reductions from buying in large quantities. Jacobsson estimates that in the long term firms manufacturing in this sector must aim to produce 1000 machines a year to reap all the benefits from economies of scale (1986: 100). However, as the Italian case has shown, economies can be achieved in small-scale production by centralising some marketing, financial, and design functions within the national manufacturers' association.

A second factor influencing both the price of components and firms' technical development is the evolution of domestic component suppliers. As noted earlier, the main Japanese controls supplier, Fanuc, collaborated with machine tool firms in early NC developments and continued to work closely with them in producing new generations of control units. It is highly probable that Fanuc's supply of control units and servo-motors to Japanese producers was also a major contributory factor behind Japan's success in low-cost, standardised CNC machine tools. Components may be manufactured by independent firms or by the machine tool builders themselves integrating backwards into the production of their own inputs. However, early entry into the manufacture of components, especially control units, is difficult in NICs which are just establishing a CNC production capability, since there is only a very small market for them. Consequently, a lowering of components price in the initial stages of production is unlikely to occur. Entering into controls production also carries very high costs since some form of after-sales servicing network must be established. On the domestic market this can be an extension of the firm manufacturing the control unit, but, if exports are envisaged, an international service network needs to be set up. It is interesting to note that in the mid-1980s several Japanese machine tool producers commenced the manufacture of their own control units. In the main, these firms had already established not only marketing networks abroad but also

production plants, giving them a good technical base in the markets where they were hoping to sell their controls. Only with an established sales network in overseas markets, or with close production links to foreign firms, could the export of control units be contemplated.

So far the only strategy considered has been the manufacture of low-cost standardised machines, as this is the easiest sector for NIC firms to enter. However, for industrialising countries in which machine tool production is promoted to provide technical support to other manufacturing industries, such a strategy is not wholly appropriate in the long term, because the technological capabilities acquired will not be adequate to offer such support. Although there will eventually be a build up of repair and maintenance skills which may be utilised in other manufacturing sectors, few of the design, development and adaptation capabilities required for the improvement of user industries' manufacturing equipment will be acquired. Nor will there be a build up of skills in plant layout and the installation of production facilities. It is the development of these latter capabilities which is critical to the introduction of new products and production improvements in other user industries, and without them the long-term competitiveness of manufacturing industries in both domestic and export markets may be adversely affected.

Indeed, both analysts and some firms in the Korean industry perceive the necessity of acquiring a broader range of capabilities (Bendix et al., 1978: 45). And in order to do so, the production strategy of the machine tool builders is obliged to take into consideration the more complex machinery required by their main user industries, including the design and manufacture of customised and special-purpose machines, lines of machines, and flexible manufacturing systems. It is not considered appropriate to attempt to produce all the types of machines required by manufacturers or to enter the very sophisticated or high-precision sectors of the market. However, some focussed strategy in a product area in which machine builders have opportunities to enhance their capabilities, and in which they may be able to reap some economies of specialisation, is necessary. The general technological requirements for

entry into such sectors are, of course, much higher than for basic standardised machinery. But entry by firms into the production of more specialised machine tools can be undertaken in the same way as more basic equipment is first manufactured, e.g., through technology transfer agreements or by copying previously imported machinery. Nevertheless, this strategy is by no means equivalent to the view that firms must try to develop machinery at the leading edge of technological developments.

In order to follow this second strategy, machine tool builders need to identify their major users' needs and attempt to manufacture machinery accordingly. This strategy, of course, carries much higher risks than the production of basic standardised machinery, and there are greater costs involved. Realistically, such a strategy can only be embarked upon in collaboration with firms in the final user industry in order to minimise risks and costs. And such collaboration only routinely presents itself when there is a highly concentrated market, such as that constituted by the vehicle industry. The formation of close technological inter-firm linkages between machine builder and vehicle producer is, as the development of the Japanese CNC industry illustrates, ultimately of benefit to both user and producer. Because of the advantages of these close links perceived by vehicle producers, several firms, particularly in Japan but, notably, also Fiat in Italy, have themselves established machine tool manufacturing divisions or subsidiaries. In such cases, although there are risks involved, the machinery manufacturing division is assured of a market.

Governments influence the strategy of firms both through their policies and as machine tool consumers. Governments may encourage firms to manufacture for certain sectors of both the domestic and export markets. On the domestic market such policies are implemented by either protecting domestic producers or subsidising their production. The promotion of specific sectors is, however, a difficult balancing act for governments to achieve. On the one side, governments want to give indigenous manufacturers some advantages in these sectors of the domestic market to enable the industry to develop manufacturing capabilities and to build up its market share. However, on the other

side, governments must be careful not to put user industries at a disadvantage, by forcing them to buy either sub-standard or very expensive machinery, which may adversely affect their productivity and/or product quality.

Governments' major machinery purchases are usually in the military sector. The extremely close defence industry links which evolved in the US, and the orientation of many US firms towards supplying this highly sophisticated and profitable market, constitute a cautionary lesson about the consequences of picking a strategy which is too narrowly defined and one in which the product or product technology is not easily switched to other sectors of manufacturing. Thus, Melman's critical analysis of military-industry links in the US might still prove useful reading for NIC governments, just as the relative lack of such links in Japan might be read as a lesson for future policies in other countries. Certain NIC governments have already begun to be careful in the formation of their defence procurement policies, giving domestic industry the chance to expand into the less specialised end of this market, but not demanding or encouraging it to become a specialist supplier of machinery which can only be consumed by the military.¹²

Notes

1. A detailed account of the increase in production in the US machine tool industry, and its immediate post-War decline, is in Wagoner (1968).
2. This statistic is taken from a recent study by Sigurdson (1986: 16) who reached the conclusion that formal R&D did not play a major role in machine tool firms, even those at the leading edge; see also DiFilippo (1986: 48).
3. The period covered by this analysis relates to the development and sales of both NC and CNC machine tools. As it is rare for any production and trade statistics to differentiate between CNC and NC machines, all statistics used in this chapter refer to both NC and CNC machines, and therefore represent controlled machine tools as opposed to conventional machines.
4. Although these machines could not be purchased from the US, some machines were available on the international market from other sources. For example, in early 1987, Toshiba supplied the USSR with a high-precision multi-axis machining centre, capable of machining very smooth propeller blades for use on naval vessels, including submarines. This sale promoted retaliatory action by the US government, which banned imports of certain Toshiba products.
5. DiFilippo details the effect of changes in US defence spending on the business cycle and on the demand for machine tools (1986: 98-120).
6. Melman suggests that where CNC machine tools are used in American plants, they tend to be utilised very inefficiently. He notes that in US factories managers have used CNC machinery to increase their control of workers by dividing and simplifying production tasks. In many cases operators are not permitted to repair their machines or change any operating parameters. This results in under-utilisation of the machines, a waste of skilled labour, and labour disputes. In contrast, CNC machinists in a Japanese machine tool plant Melman studied were able to adjust and alter the settings of machines and part-programs, in order to improve the machine's operation or to eliminate malfunctions (1983a: 62).
7. Information on Japanese machine tool production and technical agreements is derived from various articles in Metalworking. For more details, see the issues of May 1985, March 1986, and May 1987.
8. A parametron is a resonant circuit in which either the inductance or the capacitance is made to vary periodically at half the driving frequency. It was developed and used in Japan as a digital computer element, in which case each oscillation represents a binary digit (Handel, 1971: 267).
9. Much of this section is based on interviews with personnel at Ferranti, TI Matrix Herbert Churchill, the Production Engineering

Research Association, the National Engineering Laboratory (East Kilbride), and the Machine Tool Industry Research Association.

10. The Ministry of Technology, under its Minister, Anthony Wedgwood Benn, was then embarked upon the implementation of Harold Wilson's so-called "white hot technological revolution". In order to create "an industrial framework strong enough to finance its own high cost research and able to mount effective scientific marketing world-wide", a number of mixed enterprises were formed by merging existing companies. As well as encouraging the merger of controls production under Plessey and the expansion of Alfred Herbert, the Ministry also promoted the mergers of Rolls-Royce and Bristol Siddeley, and Leyland and British Motors (Benn, 1968: 651).
11. It is highly probable that many of the "European" producers of machine tools, which manufacture CNC machine tools under licensing and other production agreements with Japanese firms, do not reach these levels of EEC content, so the Yamasaki machines may be more "European" than many other CNC machines manufactured in the UK.
12. For example, Nolan suggests that "[Taiwan] has deliberately avoided engaging in production projects that might excessively tax its financial and technical ... capabilities and drain away resources needed for more immediate defense needs" (1986: 137).

Chapter Five

Korean Industrial Development

5.1 Introduction

The rapid and sustained economic development of South Korea since 1960 is well documented.¹ Per capita GNP increased from US\$82 in 1961 to US\$1,884 in 1983 (Economic Planning Board, 1984: 7). Leading this expansion was the growth of exports, which rose steadily from US\$52 million in 1962 to US\$33.9 billion in 1986, and in this year Korea also achieved its first current account surplus, amounting to US\$4.6 billion (Montagnon, 1987). The most rapid growth in exports occurred in the decade from 1970 to 1980, when exports increased at an average annual rate of 23.2% in real terms (Enos and Park, 1988: 30). The type of goods exported from Korea has also changed radically. In 1960, only 18% of total exports were manufactured goods, but in 1978 these accounted for 88% (Nam, 1981: 191). Initial export growth in the early 1960s was principally in the light industries, such as textiles and wigs. These industries used skills that Korea either already had or which could be easily acquired. Furthermore, Korea also had a comparative advantage in these industries as their factor intensities coincided with Korea's relative factor endowment, mainly cheap labour (Westphal et al., 1984a: 3). While light industry exports have continued to expand with the production of new items, such as handbags, shoes and plastic goods, since 1970 a trend has emerged of the increasing export importance of more sophisticated, skill-intensive products. After 1970, electronics, ships, iron and steel, rubber tyres, machinery, and petroleum products all became major export items.

There is no simple single explanation for the success of Korea in these more sophisticated industries. Unlike industries such as textiles, which had been established in Korea during its colonisation by Japan, and which were concentrated in the South, a high proportion of heavy industry and electricity production that existed before partition was primarily in the North (Jones and Sakong, 1980: 27). South Korean industry, therefore, had little experience or knowledge on which to base the growth of this

sector. Growth in some areas of the heavy machinery and chemical sectors was the result of backward linkages.² For example, plants producing artificial fibres were built with the intention that they would supply the expanding textile industry (Westphal, 1979: 233). But other areas, such as shipbuilding, were totally new ventures with no technological base or large domestic market to supply.

This chapter examines the development of Korea's skill-intensive industries and the factors which influenced their growth. Some factors animating Korean industrial development, such as the role of government, are in many analysts' view, common to all NICs.³ Other factors, such as the expansion of large conglomerates, are more specifically Korean. Any assessment of the development of the Korean CNC machine tool industry is obliged to take into account the overall economic, political and technological environment in which it has emerged. Government policies, and their change over time, have, without doubt, been crucial. These policies have influenced the machine tool industry through their effect on Korean industrial development in general, and they have at times been targeted more precisely on the machine tool industry itself. In addition, government has had a role in the development of the machinery sector through its security preoccupations. Changing perceptions of the contribution of a machine tool industry to the military have been a marked feature of Korean policy. But, although government has indeed, been a significant influence on industrial development in general, features that can be considered internal to the Korean industrial environment also need to be stressed. For the development of the Korean machine tool industry, a major influence has been the requirements of its largest domestic users. Indeed, one of the characteristics of the Korean CNC machine tool industry has been its orientation towards production for domestic civilian users, and in particular the vehicle industry. Arguably, that aspect of the industrial environment has been most decisive in shaping the development of the Korean CNC industry. Moreover, the conglomerate structure of Korean industry has in some cases situated machine tool producers alongside their main users, with significant consequences for innovation and technological development.

5.2 Government Industrial Policy

The general direction of Korea's economic and industrial policies have been profoundly shaped by the political and military environment. Security considerations have permeated Korea's political patterns, and these, in turn, have exerted pressure upon government's thinking about the nature and direction of economic development. Since the end of the 1950-53 War, South Korea has been led almost continuously by authoritarian right-wing governments and their policies have to a large extent reflected a fear that North Korea may invade should the South display any sign of internal strife or military weakness. With national security as its stated primary motivation, the military has on two separate occasions taken over the government. In April 1960, President Syngman Rhee's government was overthrown by a student revolution. An interim government was formed, but in May 1961 its rule was terminated by a military coup led by Park Chung Hee, who made himself President. President Park did allow an election to take place in 1972, which he only just won. Military rule was almost immediately re-imposed; the losing candidate, Kim Dae Jung, was found guilty of sedition and sentenced to death, and a new constitution was introduced which not only gave the president the ability to directly select a third of the legislature, but also guaranteed his own position by making the re-election of the president automatic. Park was assassinated in 1979; however, following large-scale student demonstrations, the military seized control again within a year and General Chun Doo Whan became President. A new constitution was introduced in 1980 limiting the president's rule to seven years. Chun did step down from the presidency in 1987, and, following a democratic election, in which the opposition vote was divided between two candidates, he was succeeded by his military colleague, Rho Tae Woo.⁴

After Syngman Rhee's fall, all Korean governments have adopted a highly interventionist role vis-à-vis the country's development patterns. The basic shape of the government's development strategy since the early 1960s has been contained in a series of five-year plans. Table 5.1 summarises the principal targets and the major industrial objectives of the first five of these plans, covering 1962 to 1986. While the first

Table 5.1 Major Targets and Industrial Objectives of Korea's Five Year Plans 1962-1986

Contents of Plans	The First 5-Year Plan (1962-1966)	The Second 5-Year Plan (1967-1971)	The Third 5-Year Plan (1972-1976)	The Fourth 5-Year Plan (1977-1981)	The Fifth 5-Year Plan (1982-1986)
Plan Targets	1. Correction of vicious circle of social and economic aspects. 2. Establishment of the foundation of self-sustaining economy.	1. Modernisation of industrial structure. 2. Acceleration of self-sustaining economy.	1. Balanced growth stabilisation and a balanced economy. 2. Realisation of self-sustaining economic structure. 3. To ensure balanced regional development.	1. Growth, equity and efficiency. 2. The creation of economic structure for self-sustaining growth. 3. Promotion of social development. 4. Technological innovation and raising efficiency.	1. Stabilisation, efficiency, and balance. 2. Completion of the foundation for economic stabilisation. 3. Increase in job opportunity and income. 4. Promotion of national welfare.
Principles of Industrialisation	Adjustment of the foundation of industrialisation.	Outward-orientated industrialisation.	The build-up of export-orientated heavy and chemical industries.	Development of technological and skilled-labour intensive industries.	To attain a stage of advanced industrialisation.
Development Strategy of Manufacturing	Nurturing of basic industry and adjustment of social overhead capital (establishment of foundation for self-sustaining industries).	Capital goods import substitution and exportation of light manufactured goods (outward looking industrialisation).	The build-up of heavy and chemical industries (change in industrial structure).	Change in industrial structure and promotion of competitiveness (realisation of economic structure for self-sustaining growth).	Advanced industrialisation as seen in developed countries (development of intelligence and information intensive industries).
Industrial Sectors Emphasised	Electricity, fertilisers, oil refining, synthetic fibres (nylon yarn), cement, PVC.	Synthetic fibres (polyester yarn), petrochemicals, electrical appliances (TV and refrigerator).	Iron and steel, transport machinery, household electronics (TV transistor), shipbuilding, petrochemicals.	Iron and steel, industrial machinery and equipment, electronic appliances components, and parts, shipbuilding.	Precision machinery, electronics industry, intelligence and information industries.

Source: Korean Business Review, Sept. 1986: 43-46.

plan was formulated by a few civilian advisers to a ruling council, subsequent plans were drawn up by members of the government and many advisers, including representatives of foreign aid missions; officials in the national banking institutions, economic research institutes, and various industrial associations; academics and journalists (Jones and Sakong, 1980: 49-51). Each plan stressed the development of strategic industries, the modernisation of the country's industrial structure and infrastructure, and the creation of social welfare and educational structures capable of supporting these developments. The plans set targets for growth in industry, agriculture, and education, and put in place a series of incentives to achieve these goals.

In the 1960s and 1970s, the Korean government used a complex system of industrial incentives to promote growth. Selected industries were promoted for import substitution, and these were given almost total protection by the government. In the main these measures were biased towards industries in the primary goods sector and agriculture. Within the manufacturing sector, where domestic demand was too small to justify the establishment of economically sized production plants, exports were encouraged by a series of incentive measures.⁵ In the mid-1960s, these incentives included automatic exemption from import duties and indirect taxes on intermediate goods, parts and components to be used in export products; generous wastage allowances on raw material imports (already exempted from duty and indirect taxes), which could be used for production for the domestic market; reduced prices for a range of overheads, including electricity and rail transport; tax reductions on export income, with a provision for accelerated depreciation; easy and immediate access to subsidised short- and medium-term credit; and, intermittently, an export-import link allowing exporters to import popular, but technically prohibited, items (Westphal, 1979: 237). Indirect exporters, which provided intermediate inputs for exporting firms, benefitted from these incentives. Leading exporters were also given presidential prizes, citations and awards, which, although they did not in themselves carry any tangible benefit, were taken seriously by industrialists as they accorded public recognition and some indication that they might secure further financial support (Rhee et al., 1984: 17).

Many of these export incentives and allowances were not considered as direct subsidies, but merely gave Korean producers tax parity compared with other world producers. In effect, the measures allowed export producers to operate under a virtual free-trade régime (Kim Kihwan, 1984: 5; Nam Chong Hyun, 1981: 192). Since such measures favoured export producers over those manufacturing for the domestic markets, these government policies were, therefore, an important factor in the expansion of Korean export production. But there were also measures designed to protect areas of the domestic market and to encourage import substitution, especially in the basic materials used in industrial production.

The introduction of government incentive measures to encourage exports was not, of course, unique to Korea. However, their particularly effective application appears to have been the result of very close links between government and business. Rhee et al. analyse two mechanisms introduced by the government in the early 1960s which they consider to have worked as catalysts in the efficient application of incentive measures. Firstly, export targets, which were projections made by the firms, had to be submitted to the government. Firms' combined export targets were used by the government as a basic measure of expected growth and as a means of planning future financial and infrastructural requirements. Targets were also sometimes used informally for the allocation of specific incentives. And, secondly, monthly meetings, chaired by the president and attended by both economic ministers and industrialists, were held to review progress towards the targets. These meetings provided an important forum for the industrialists to negotiate with government on incentive measures and to discuss developments in international trade (Rhee et al., 1984: 15-38). Through its control of the banking system and inflows of foreign financial resources, the government was also very effectively able to control which firms were given loans.

By the early 1970s, it became clear that these incentives were yielding excessive profits for export producers. In 1973, the government abolished a number of incentives, including the lower direct tax rates and

the automatic tariff exemption on imported capital goods, while other incentives, such as wastage allowances and interest subsidies, were reduced (Westphal, 1979: 266). And in 1975, automatic access to import tax relief was stopped; exporting firms had to pay the taxes and then reclaim them. The government did not entirely abandon export producers; indeed, it introduced new measures for their benefit: the Export Insurance Law in 1968 reduced exporters' risks; the Export-Import Bank was established in 1976 to supply credit to exporters on a medium-term basis; and preferential loans for export industries continued to be increased throughout the period (Nam, 1981: 193).

From the early 1970s, the government started to actively promote the heavy, machinery and chemical industries manufacturing primarily for indigenous consumption. The government wanted to adjust the structure of Korean industry from one dominated by light industries to one with a greater balance between heavy and light industries. The apparent need for this adjustment and re-structuring arose from several developments. Firstly, with wages rising in Korea and more competition from other industrialising countries, the well-established light industries, which had dominated Korea's industry and exports, were losing their competitive advantage (Nam, 1981: 191). Secondly, there was rising protectionism abroad against light industrial products, the effect of which was to limit the further expansion of Korea's exports (Westphal, 1979: 235). Finally, the government was anxious to develop an indigenous defence industry. American foreign policy crucially influenced the government in this rush to develop the defence sector. The Nixon Doctrine of the late 1960s planned a reduction in the quantity of arms supplied to Korea and in the number of troops stationed there. This was followed by the Carter administration's troop-withdrawal plan in the mid-1970s, which was, in fact, never carried through. Both these plans were accompanied by commitments, in the form of a series of co-production agreements, from the US administration to help Korea build up its own defence industry (Nolan, 1986: 24-34; Kim Kihwan, 1984: 9-10). But the Korean government's nervousness about the possibility of abandonment by its major ally manifested itself in an increasing military focus of its national industrial policy.

In the Third Five Year Plan (1972-1976), the principal industrial sectors promoted included iron and steel, transport machinery, household electronics, shipbuilding, and petrochemicals. A far greater number of heavy and chemical industries were selected and given priority status in the Fourth Five Year Plan (1977-1981). Table 5.2 shows these industries and the promoted sectors within them. Of these specially designated industries, the machinery industry was given the "highest industrial investment priority in the plan" (Government of the Republic of Korea, 1976: 42).

Table 5.2 Priority Industries in the Late 1970s

Industrial Sector	Specific Products to be Promoted
Steel	Foundry Products, Forgings, Special Alloy Steel, and Seamless Steel Pipe
Non-ferrous Metals	Refining of Copper, Zinc, Lead, and Aluminium
Machinery	Tools, Dies, Hydraulic Devices, Gears, Transmissions, Bearings, Bolts and Nuts, Automobile Components, Marine Machinery, Metal Working Machinery, Textile Machinery, Chemical Machinery, Electrical Machinery, Anti-pollution Equipment, and Atomic Power Generating Facilities
Shipbuilding	
Electronics	Transistors, Integrated Circuits, Basic Materials, Household Appliances, and Industrial Equipment (Computers)
Chemicals	Petrochemicals, Soda Ash, Fertilizer, Pulp, Ethylene, Polyethylene, Styrene Monomers, Octanol, Butanol, and Glycol

Source: Business International Asia/Pacific, 1979: 121.

In promoting the heavy and chemical industries, the government used a multitude of incentive measures. In 1974, the National Investment Fund was established to provide loans at less than market interest rates to finance the purchase of plant and equipment, and in some cases to provide working capital. The government also stimulated domestic demand by

making loans available through easily accessible special-purpose funds (Kang Youngkook, 1984: 2). Low-interest loans allocated to the priority sectors of industry (i.e., the heavy chemical and machinery industries) through these various funds accounted for approximately 50% of total bank lending in the mid-1970s and were concentrated on several large firms (UNIDO, 1987: 48). Under an act passed in 1973 for the promotion of industrial complexes, the government invested in the establishment of new industrial sites - electronics at Gumi, machinery at Changwon, a chemical industry base at Yecheon, a shipbuilding centre on Koje Island, and, in the late 1970s, a complex for small and medium industries at Banwol. On all these sites, the government paid for infrastructure (e.g., transport facilities, water and electricity supplies, etc.). Other fiscal policies included reduced corporation tax for certain strategic industries, accelerated depreciation, tax exemptions on R&D investments, and tax rebates on imported raw materials used in export goods. Again, through its control of finance, the government could to a very large extent direct new investment. There is also considerable evidence that the President personally encouraged individual firms to enter specific industries (see, e.g., Jones and Sakong, 1980: 119-20).

In order to protect the domestic market, quantitative measures were used in preference to the imposition of tariffs. The level of protection in strategic industries was increased; in the machinery sector the import liberalisation rate dropped from 56% in 1968 to 36% in 1976 (Koo Bohn Young, 1984: 12).⁶ For products which had achieved a certain degree of localisation, the government automatically imposed measures to protect the domestic market. However, if locally manufactured equipment was judged to be of exceptionally poor quality, the import of these goods was made relatively easy. But the tax exemptions on such items were kept low in order to stimulate higher quality domestic manufacture (Amsden and Kim, 1986: 117). In certain sectors, such as car production, the market was totally protected and all imports were strictly prohibited.

The actual regulation of the machinery industry, its promotion and protection, was to a great extent delegated to a parastatal organisation, the Korean Society for the Advancement of the Machinery Industries

(KOSAMI), which had been established in 1968 under a section of the Machinery Promotion Law.⁷ Membership of the society includes all enterprises in iron and/or non-ferrous manufacture, a definition which was intentionally very broad so as to include nearly all mechanical engineering industries but to exclude primary material manufacturers. An important feature of KOSAMI's role in the development of the machinery industry was that it was entrusted by government to act as a government-surrogate in several spheres. KOSAMI could issue import permits for items on the government's prohibited import list if they were needed by one of its members. The import of large machinery was also regulated by KOSAMI, which had to pass all machinery imports valued at over US\$1 million. Permission could be refused if KOSAMI considered that the machinery could be produced domestically. KOSAMI, therefore, represented both users and producers in its policing of imports and in its decision making it had to reconcile the demands of both.

KOSAMI was also entrusted to designate new domestically developed machines as the first indigenously produced machines of that type and to implement a localisation plan for the production of domestic machinery. These designations were important to producers, since some additional incentive measures were dependent on them. From 1968 to 1981, KOSAMI operated a Quality Guarantee Fund, which ensured the quality of machinery sold against defects in materials or manufacture. This was financed by the machinery producers who were required to deposit 10% of their sale receipts in the fund.

In the early 1970s, these measures for the promotion of heavy industry were focussed on import substitution, with the ultimate intention of reducing the country's dependence on export activity. But in later policy revisions, and in the Fourth Five Year Plan, exports from the heavy sector were encouraged. This change in policy reflected the need to take advantage of economies of scale in production, which could only be achieved if a significant proportion of the goods were exported (Westphal et al., 1984a: 10).

As well as directing domestic industries, the Korean government has also controlled direct foreign investment in Korea. In the 1970s, the government introduced measures to restrict the entry of foreign producers, limiting the amount of equity foreign investors could hold in Korean companies and setting minimum investment levels for various industries. Wholly-owned foreign subsidiaries were not totally prohibited, but joint ventures with Korean firms were given priority in receiving government approval. Most of the wholly foreign-owned projects and the joint ventures approved in the 1970s were located either in the government-established free-trade zones or in priority industries on the government's specialised industrial complexes. In general, wholly foreign investments were only approved if the new developments, or the technologies used, were in a priority category. In a very few sectors, including electronics, the Korean government has actively attracted foreign investment, by giving foreign investors privileges not offered to domestic producers (Business International Asia/Pacific Ltd., 1979: 123).

Measures to encourage technological development and to control the import of foreign technology were also introduced. In the early 1960s, government-run research organisations were operated separately under relevant ministries. The major activities undertaken by these organisations were limited to providing testing and analysis services. The main constraining factors were the small size of each institute, and their lack of equipment and facilities (Kwon, 1986: 2). In the late 1960s and early 1970s, the government introduced numerous acts for the establishment of research and development institutes.⁸ To raise the overall level of R&D, and to rationalise the existing spread of the government's R&D efforts, the Korean Institute of Science and Technology (KIST) was established in 1966. There were similar problems of co-ordination in scientific and technical post-graduate education, as only a few post-graduates were being trained at many different universities and colleges. To alleviate this problem, and to increase the number and standard of post-graduate students in these fields, the government created the Korean Advanced Institute of Science (KAIS) in 1971. KAIS was located near KIST so that the two institutions could easily collaborate. Both KAIS and KIST were set up under similar laws which

guaranteed autonomous management of the organisations, even though funding was through government endowment.

By the mid-1970s, KIST could no longer meet the increasingly diversified technological demand from the industrial sector. Separate specialised research institutes, intended to work with specific industries, were established under a general statute. The new dedicated research institutes included laboratories concentrating on shipbuilding, standards, metals and machinery, electronics and telecommunications, and chemical technology. Many of these new research organisations were "spin-offs" from existing research groups at KIST. In 1981, the structure of research organisations was again altered by the government, which integrated and re-aligned the sixteen existing institutes into nine new institutes, whose activities were to be co-ordinated by the Ministry of Science and Technology (MOST). Under this reorganisation plan, KAIS and KIST were amalgamated to form KAIST (Korean Advanced Institute for Science and Technology). The research work undertaken at KAIST was to be more fundamental and the results of KAIST's work were "expected to be used by specialty institutes and private R&D institutions, rather than directly by the industry in the production lines" (Kwon, 1986: 8). Other laws encouraged the development of vocational training colleges and universities, and promoted technology and engineering services in industry.

The import of technology was regulated by several acts, of which the Foreign Capital Inducement Law, an act that also regulated foreign investments, was the most important. Under this Law, technologies were screened and rated by the Economic Planning Board (EPB) as to their desirability. Highest priority was assigned to technologies with great potential to expand exports; technology for manufacturing components and for new processes for the capital goods industry came next, followed by technology which would be very costly or take a long time to develop domestically; and, finally, there were technologies which had the potential to promote cost reductions and productivity increases (Enos and Park, 1988: 36). Technologies outwith these requirements could be imported if provision was included guaranteeing the quality of the product and

specifying that any technological improvements by the licensor would automatically be transferred to the Korean licensee. Regulatory clauses, such as limits on export markets (where the licensor did not have exclusive selling rights), and the regulation of access to competing technology and products, were actively discouraged in the approval process.

In general, technology agreements were further limited to a duration of three years and payments to less than 3% of net sales. In several cases, where licensees and licensors applied for an extension of a further three years, permission was withheld by the EPB. For example, in 1973 Foremost McKesson of the US and Daeyle Dairy Products of Seoul entered into an agreement containing technical assistance and the use of a trademark. In 1976, the two firms applied for a renewal of the agreement, but this was rejected by the EPB. Daeyle ceased using the Foremost trademark and formal technical links ended, although an informal relationship remained (Business International Asia/Pacific, 1979: 133).

In early 1978, the government liberalised licensing approval in seven priority industries: machinery, chemicals, electronics, electrical power, metals, shipbuilding, and textiles. Agreements in these sectors were automatically approved if the contract was for less than three years and if royalty payments were either less than 4% of advance sales (without advance payments), or less than 3% (with an advance payment below US\$30,000), or if only an advance payment of less than US\$100,000 was made. In 1979, regulations were further relaxed to allow automatic approval in all sectors except the defence and atomic power industries, providing the agreements were for less than ten years and the royalties were either less than 10% of sales, with a maximum advance payment set at less than US\$500,000, or only a single advance payment of less than US\$1 million. For agreements outwith these limits, the time taken for the EPB to grant approval was to be reduced from two months to a week (Business International Asia/Pacific, 1979: 132). While these regulatory changes reflected government's desire to encourage the import of new technologies, as well as its recognition that the majority of producers had built up adequate experience in negotiating technology agreements,

they also reduced the number of agreements that had to be screened by the EPB and hence made its work more manageable (Enos and Park, 1988: 37).

Although the government passed these measures to facilitate the import of new technologies, it still maintained the power to reject agreements if they were considered to be against Korea's interests. Outdated technologies, and technologies which might cause excessive competition on the domestic market, were thus excluded. Technologies which had been selected for domestic research and development efforts were also discouraged. In this field, MOST was delegated with the responsibility of assessing the level of technical know-how in Korea and the desirability of the new technology. Together with these responsibilities, MOST was given the power to object to technology agreements, even if they were in a category which allowed them to be automatically approved (Business International Asia/Pacific, 1979: 133).

Promotion of the heavy and chemical industries in the 1970s was not as successful as the general promotion of export industries had been in the previous decade. Up to the mid-1970s, only a few heavy industries were promoted at a time, such as shipbuilding and steel production, but in the late 1970s many more heavy industries were encouraged simultaneously. This led to a concentration of credit in several large firms in the heavy and chemical sector and, thus, weakened the development of the export-led sector. By the late 1970s, many of the large enterprises were in financial difficulties, and in 1978 "the top economic planning minister was charged with the overriding objectives of reducing inflation and salvaging the mistakes in heavy industry" (Rhee et al., 1984: 68). One of the major contributory factors to the difficulties in this sector was the government's optimistic assessment of the size of the potential market. The domestic market did not grow as quickly as had been anticipated, and, as the plants were not competitive on the world market, exports did not reach the levels planned. This was principally due to the over-valuation of the Korean currency, high wage rises, and insufficient investment in the development of technology and skilled manpower (Koo Bohn Young, 1984b: 16). These circumstances led to

over-capacity in many plants. To salvage as much as possible, the government reorganised the heavy sector by transferring the ownership of some firms, forcing some competing firms to merge, and limiting the number of firms allowed to specialise in certain sub-sectors of the industry (Rhee et al., 1984: 68). These domestic industrial problems were exacerbated in 1979 by the assassination of President Park, the second oil crisis, and, in 1980, a disastrous harvest.

Government policy in the early 1980s continued to reflect re-adjustment from the distortions in the economy which became manifest in the late 1970s. The main objectives of new policy were to improve labour productivity in manufacturing, encourage the mobility of both domestic savings and direct foreign investment to areas where productivity gains were possible, and to utilise resources, notably capital, more efficiently by enhancing allocation mechanisms. The major thrust of these policy measures was towards liberalising the economy. Regulations on direct foreign investment were relaxed, so that all investors not seeking special tax exemptions, and with equity of less than 50% in projects of under US\$1 million, were automatically approved, unless the industrial activity was on a restricted list. About a third of the total number of industrial sub-sectors were subject to restrictions, but it was anticipated that by 1988 only 10% would remain restricted industries. Limitations on imports were to be reduced, and the import liberalisation rate was to increase from 80% in 1983 to 95% in 1988. Tariffs were also to be reformed so that the average tariff rate would drop from 21% in 1984 to 17% in 1988 (UNIDO, 1987: 51). Part of this change in policy on the protection of the domestic market was a reaction to protective moves by several countries, notably the US, where Korea had important markets.

In the 1970s, most Korean industrial development and growth took place in the large conglomerates or *chaebol*, and indeed they had been the principal recipients of government loans and export finance. In order to counter this uneven development, in the late 1970s and 1980s the government introduced measures to restrict the further expansion and diversification of the *chaebol* and promote the growth of small- and

medium-sized independent firms. In 1978, the Small and Medium Industry Promotion Corporation (SMIPC) was created to aid the establishment and development of small firms, and to offer them marketing and technological services. And in 1984, the Ministry of Trade and Industry announced that intensive support would be available for 1000 small firms, with particular support for those entering the production of parts and components. Under this scheme, these firms would be given a range of incentives, including tax reductions on the purchase of new machinery (lower reductions applied for the purchase of imported machinery than for the purchase of domestically produced machinery), and expenses on technological guidance would be tax deductible (UNIDO, 1987: 55).

Even though the guiding principle behind government industrial policy in the 1980s has been one of laissez-faire, the government has still intervened when it felt competition was becoming excessive or when it wanted to rationalise declining industries. For example, in 1986, over 40 companies in financial difficulties were merged, by government arrangement, with other more successful companies. The latter were, in return, given various tax and loan incentives by the government for taking control of the declining companies (UNIDO, 1987: 52). Specific illustrations of this type of intervention, and the reduction of competition on the domestic market, are given later in this chapter and in Appendix 2. Compared to other countries, the Korean government is still very active in controlling industrial activity, and, even though the banks are now in private hands, it has maintained some controls on credit allocations (Kuznets, 1985: 64).

In order to fund this industrial development, the Korean government has relied on foreign financing. Up to the mid-1960s, grants made up a significant proportion of foreign financing, but Korea has subsequently borrowed heavily. At the end of 1966, Korea's cumulative debt was US\$300 million in medium- and long-term loans, rising to US\$7 billion by the end of 1976, and to US\$47 billion by 1985. (In 1985, Korea had the highest per capita level of debt of all developing countries.) Up to 1986, when it enjoyed its first balance of payments surplus, Korea also had large

deficits, averaging 7% of GNP in the late 1960s and 5% in the early and mid-1970s (Hasan and Rao, 1979: 6; Harris, 1986: 38).

The military origins of Korean governments since Syngman Rhee have already been noted. The security preoccupations of these governments have been manifested in their attitudes towards economic growth. Such growth has been a major government objective, not only for its own sake, but also as a way of damping down political unrest and minimising displays of internal divisiveness that might be thought to increase the risk of invasion from the North. Thus, the Korean government has consistently and vigorously intervened in order to direct national industrial development. In its control of development, it has been referred to as a "hard state", ensuring the implementation of its policies by discretionary measures and, when required, by direct command (Kuznets, 1985: 51-52). The effectiveness of government intervention has been enhanced by the extent of its control of the banking system and the allocation of credit, enabling it to target its favoured sectors (Westphal et al., 1984a: 12). Although the government was highly instrumental in industrial development, it maintained close contact with industry through forums such as the monthly trade promotion meeting, which were attended by the President, ministers and industrialists. The information gained in such meetings enabled the government to adjust and refine its policy measures accurately and rapidly (Rhee et al., 1984: 35-36). In the 1960s, government policy promoted the expansion of export production, and, in the 1970s, the heavy and chemical sector. Measures in the 1980s have reflected the changed policy of promoting industrial development in general, rather than promoting only selected strategic industries. In the main, the measures introduced by the Korean government were aimed at encouraging and directing private industry to enter new industrial sectors, instead of establishing large public enterprises for these purposes. There were, of course, exceptions: for example, the government created a public company to enter the steel industry, giving it a monopoly in the sector. But public enterprises accounted for only 15% of total manufacturing during the 1970s (UNIDO, 1987: 49).

5.3 Government Promotion of the Machine Tool Industry

Although the main thrust of government planning moved towards the heavy machinery and chemical sectors in the early 1970s, it was not until 1976 that many specific industries were emphasised. In part, these industries were chosen because of the lead they could take in the overall development process. The Fourth Five Year Plan for 1977-81 announced that,

In an effort to create more employment opportunities and to upgrade the manufacturing structure with desirable forward and backward linkage effects, top priority will be given to the development of technology and skilled labor intensive industries [such] as machinery, electronics and shipbuilding (Government of the Republic of Korea, 1976: 31).

Of the six industries chosen as main priorities at this time, the machinery industry was stressed as the highest industrialisation priority, and, within the machinery industry, further encouragement was given to certain sectors.

The promotion of the machinery industries will be concentrated on the development of strategic items in the following categories: basic materials, machine parts, machine tools, and industrial machinery (ibid.: 43).

The machine tool industry was therefore clearly seen as one of the government's highest priorities during the late 1970s. In this plan, the value of output of machines and machine parts was set by 1981 to rise to four times 1975 production levels, and export levels were set to rise to five times their 1975 level.

In 1977, the government published a detailed sub-sectorial plan for the machine tool industry - The Basic Development Plan for the Machine Tool Manufacturers.⁹ This plan set a machine tool production goal of US\$166 million, an export goal of US\$66 million, and a self-sufficiency ratio of 74% for 1981. Within the plan, machine tools were divided into three categories. Group 1 covered all the basic conventional machine tools of medium precision, most of which were already being manufactured in Korea. This group was to be specifically promoted for export. The

second group contained more complex machines, special-purpose machines, automatic lathes, gear-cutting machines, and some milling machines. This category included many machines that were not being produced in Korea, and entry into these products was to be promoted in order to replace imports. Group 3 consisted of high-precision and highly automated machine tools, which are R&D intensive to develop and which were not, therefore, included in the short-term development plan. Of the machine tool firms in Korea, some were selected as manufacturers of general machine tools (i.e., Group 1), and others were selected as specialised manufacturers (i.e., Group 2). Both types of selected firms were expected by the government to export a certain portion of their production. And the general manufacturers were also expected to develop and produce new types of machines within a specified time limit. Significantly, CNC machine tools were included on this list of machines to be developed.

The numerous measures introduced by the government in the 1970s to promote and protect the growth of the heavy machinery and chemical industries were all used in the promotion of the machine tool industry in the late 1970s. The domestic machine tool industry was totally protected, with all of the 63 items classified as machine tools at the CCCN 8-digit level being restricted (Jacobsson, 1984: 226). And, as noted above, KOSAMI was given the power to issue import permits for prohibited machinery items. Thus, an organisation representing the interests of both the machinery producers and users had control of which machinery items could be imported and which could not. A less important method of protecting the domestic market was the use of tariffs. In 1981, the tariff rate on imported general machinery was 10.4%, and 14.8% on precision machinery (Kim Seung Jin, 1983: 12). These tariffs were similar in magnitude to those used by Taiwan at the same time, but were much lower than those applied by some other developing countries (for example, India).

Domestic machinery producers were directly and indirectly subsidised through various government-run schemes. Tax subsidies were offered on corporate and personal taxes. Capital was supplied to the industry at low interest rates through preferential loans from the

National Investment Fund (NIF) and the Korea Development Bank. According to Jacobsson (1984: 227), exporters of machine tools were considered more favourably when these credits were allocated. Furthermore, an industrial complex for the production of machinery was established at Changwon. The government financed the building and operation of the site, including all the infrastructure, thus effectively subsidising the firms which established new plants there.

To increase domestic demand for machinery products, the government introduced several measures. Preferential loans were extended to the consumers of machinery products through the Machinery Localisation Fund, the Plant Localisation Fund, and the Used Machinery Replacement Fund (Kang Youngkook, 1984: 3). Special tax exemptions and depreciation allowances were also available to purchasers of domestically produced machine tools (Jacobsson, 1984: 227). All government institutions and industries were instructed to buy machinery from designated domestic manufacturers on a priority basis (Bendix et al., 1978: 44). Exports of machines were also assisted through the Export-Import Bank and the Export Industry Machinery Fund, which supplied long-term export credit for foreign buyers.

In the government's reorganisation of its research institutes in 1976, the Korean Institute for Metals and Machinery (KIMM) was established to support the design and development work of the machinery industry. KIMM provides technical support to the machinery industry, and also tests and inspects machinery products, including machine tools, for export under the Korean Export Products Inspection Law. The work undertaken by KIMM is directly linked to industrial needs - often the specific needs of a particular firm. The major support offered consists of prototype development, industrial consultancy, and the provision of test facilities. KIMM also has a role in training, and in the dissemination of technical information through organising seminars and courses for industry (Barrow, 1983: 10). KIMM's other main function with regard to the machine tool industry was to inspect machinery and components, under the standards set out in the Korean Industrial Product Quality Control Law, the Korean Export Production Inspection Law, and the

Korean Industrial Standards. An NC centre was set up within KIMM, under a UNIDO development plan in 1983, to provide "various technical supports for the implementation of NC machines" (KIMM, 1985: 12). Projects within the centre include software development, robotics, CAD/CAM, and detailed analyses of machine tool structure. To enable this institute to work closely with machinery producers, the relevant departments are located in the centre of the machinery complex at Changwon.

Incentive schemes were introduced to encourage manpower training and the acquisition of new technology. A proportion of firms' R&D expenses and training costs could be deducted from corporate income tax. In the case of investment in increased capacity using new technologies, firms had a choice of a tax deduction on the initial outlay or special depreciation allowances. Research equipment imported by the government research institutes was exempted from tariffs. Donations given to these institutes by firms could be treated as expenses for taxation purposes. On all new technologies imported by firms, any fees and royalties paid were totally deductible from corporate taxes for the first five years of use, after which an allowance of 50% for the next three years was made. Foreign engineers employed by domestic firms were exempted from personal income tax. Income from royalties originating in technology transfers was also exempted from tax for the first five years. In the case of machinery classified by KOSAMI as "Newly Developed Indigenous Machines", more preferential loans were available for their production and purchase in order to encourage technical development (Kim Seung Jin, 1983: 17-31).

As noted earlier, the government set goals for the growth of the machine tool industry in its 1977 plan. The figures in Table 5.3, show that machine tool production in the late 1970s grew rapidly, and in 1981 production surpassed the level anticipated. But exports and the self-sufficiency ratio were less than half the anticipated values. 1981 was, however, a year of very high machine tool consumption in Korea and a large proportion of the demand was for specialised equipment for the vehicle industry which had to be imported. Thus, while the industry grew in line with government plans, the government overestimated its export potential and underestimated the size of the domestic market.

There is some evidence that, of the industries selected for promotion in the mid-1970s, the machinery sector was the greatest beneficiary of government policy. Firstly, the level of protection of the domestic machinery market was higher than for most other industrial sectors. Kim Seung Jin (1983: 4-8) compares import liberalisation rates to show that the machinery industries were consistently protected to a greater extent than manufacturing industry in general. His analysis also shows that, of the machinery industries, the general machinery sector, which includes machine tool production, was more highly protected than other machinery sectors, and only one sector, the electrical machinery industry, enjoyed greater protection.

Secondly, as already noted, the parastatal KOSAMI functioned as a practical arm of the machinery industry in protecting the domestic market. KOSAMI could reject the importation of any machinery and could waive import restrictions to remove impediments to the progress and competitiveness of a member firm. Thus, to a large extent, the machinery producers themselves were able to regulate levels and types of machinery imports. While most other countries' governments consult organisations representing machinery producers on the implementation of protection, and especially the equipment which should be included in such measures, the responsibility for implementing such measures is more commonly the prerogative of a government department.

Thirdly, although there are no detailed data available on the exact distribution of economic development funds from government to the machine tool industry, some indication of the perceived importance of this industry and its products can be gathered from a range of sources. Moore (1980: 12) shows that in 1979 the total subsidy in interest rates given by the government, for distribution to all industries, amounted to 70 billion won. Of this, the heavy and chemical industries received about two-thirds of the subsidised loans: the largest loans were for the purchase of domestic machinery and for the construction of machinery factories. Indeed, two large machine tool producers received substantial loans from the government (Jacobsson, 1986: 181), and the case study in

Chapter 6 documents several instances of government loans and incentives to particular machine tool producers.

The government's support for the machine tool industry continued in the early 1980s. In the 1981 Basic Plan for the Advancement of the Machinery Industry, the metal working machinery industry was labelled as a "leading export machinery industry" and machine tools were designated as "one priority item to be assisted" (Jacobsson, 1986: 180). But by the mid-1980s, the emphasis of government policy moved from the provision of preferential low-interest loans for strategic industries to the support of general technology and product development, and increased the provision for small and medium-sized firms. Although some tax exemptions and preferential loans were still available, they were on a smaller scale. Government policy also encouraged increasing competition in the domestic market and the competitiveness of Korean products with foreign goods. As part of this liberalisation of trade, KOSAMI's right to reject the import of machinery of high value was abolished and was replaced by a reporting system. Under this system, firms had to inform KOSAMI of the import of machinery on a list of specific equipment, and KOSAMI could then try to encourage the firms to source the equipment domestically if feasible. KOSAMI only had a limited influence over which items were kept on the list, and its spokesman suggested that, as most of the machinery industry had not yet advanced from the infant stage, liberalisation would make it hard for some producers to survive. The tariff rates on imports, including machinery, were also reduced: the average tariff rate was 22.6% in 1983, to be reduced to 16.9% by 1988 (Wang In-Joung, 1987: 26).

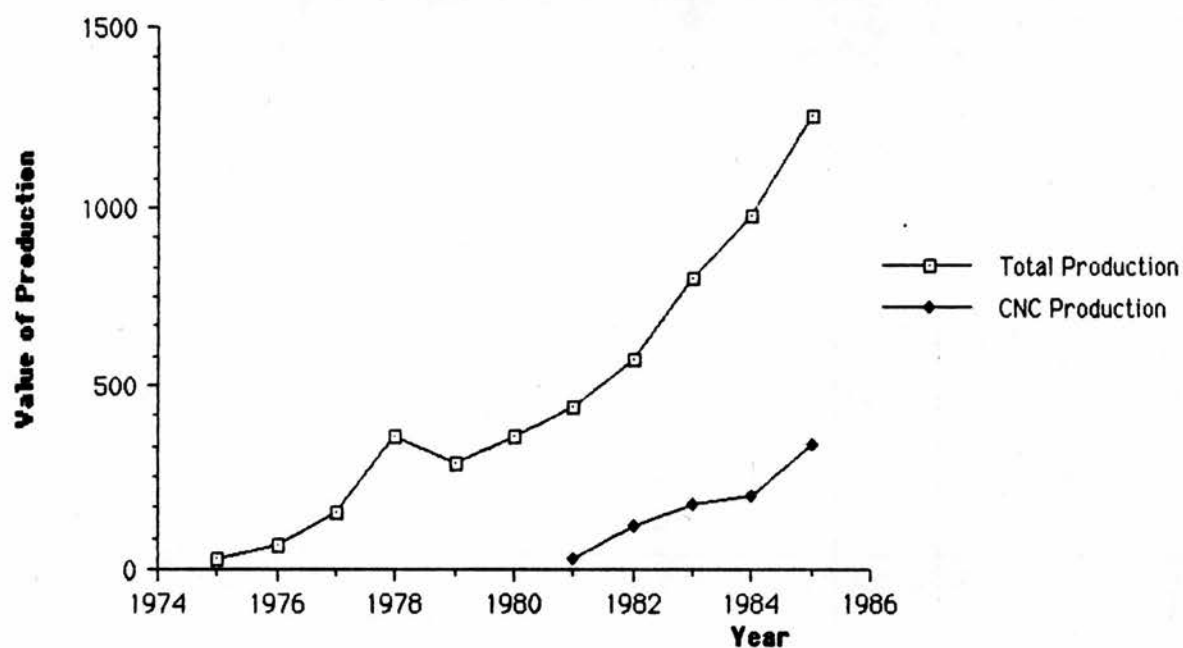
5.4 Development of Technology-Intensive Industries

From the early 1970s, the Korean government actively encouraged the heavy machinery and chemical industrial sectors. A prime example of the rapid industrial expansion and acquisition of technologies is the development of the state-owned Pohang Iron and Steel Co. Ltd. (POSCO). In 1973, POSCO commenced production at its first integrated steel mill, with an annual capacity of one million tons, the technology, and the majority of the equipment, for building and operating the mill being supplied by a Japanese company. After a series of expansions, by 1983 POSCO had an annual capacity of 9.1 million tons, and the final upgrading of facilities to reach this level was undertaken using the company's own accumulated technological capabilities (Korea Exchange Bank, 1984: 169; Park Woo Hee, 1983: 83). The POSCO experience was not unique among Korea's technology-intensive industries, and this section examines the expansion of four sectors of these industries: machine tools, defence, vehicles, and electronics.

5.4.1 The Machine Tool Industry

While a detailed analysis of the modern Korean machine tool industry is the subject of the next chapter, the basic features of its historical development, especially in relation to government and other industries, can be briefly summarised. Although the Korean machine tool industry originated in the late 1940s, it remained a very small sector of local industry until the mid-1970s. Its products during this period were very simple: engine lathes and basic milling machines. Following the government's encouragement of the heavy machinery and chemical industries from the mid-1970s, the machine tool industry has grown very rapidly. In the decade from 1975 to 1985, the value of metal cutting machine tool production rose from 30 million to 1,257 million won (see Figure 5.1). There has also been a significant increase in the production of CNC machines and in the proportion of CNC machine tool production to total machine tool output. The value of CNC production increased from 32 million won in 1981 to 338 million won in 1985, and the proportion of CNC production, which commenced in the late 1970s, increased by 1985 to

**Figure 5.1 Korean Production of Metal
Cutting Machine Tools (in 100 Million Won)**



Source: Metalworking, Nov. 1986: 144.

over a quarter, by value, of total machine tool production. In global terms, the size of the Korean machine tool industry is still small: in 1985, Korea manufactured less than 1% of world production. In the same year Japan, the largest producer, manufactured nearly thirty times Korean output, by value, while Taiwan, the leading NIC producer, manufactured 40% more than Korea (American Machinist, Feb. 1986: 89).

With the expansion of manufacturing in Korea, and, in particular, with the government-promoted growth of the machinery sector, domestic demand for machine tools has also increased. As already noted, the purchase of domestically manufactured machines was encouraged by the government which introduced several schemes to subsidise their purchase. In addition, sectors of the domestic market in which manufacturers were able to produce machines of a satisfactory standard were also protected. Thus, Korean machine tool manufacturers benefitted from growth in domestic consumption. This increase in domestic demand has also made Korea one of the largest consumers of machine tools; in 1985, it was the twelfth largest machine tool consumer in the world (American Machinist, Feb. 1986: 88). (Table 5.3 shows consumption of all types of metal working machine tools for the years 1976 to 1985.) One feature which this table shows particularly well is the cyclical nature of demand for machine tools, a point noted in earlier chapters. Domestic consumption rose rapidly in the late 1970s and then declined even faster in the early 1980s, before rising again in the mid-1980s. The first rise in consumption coincided with large-scale investment in the heavy and chemical industries. The decline in demand in the early 1980s was due to the crisis in the Korean heavy industries, in part due to over-capacity. Demand increased again in the mid-1980s with rising investment, mainly in the expansion of production capacity in the vehicle industry.

Table 5.3 Korean Trade Statistics for Machine Tools (Cutting and Forming)

Year	Production (P)	Imports (I)	Exports (E)	Consumption (C=P+I-E)	P C	I C	E P
	<----- (in million US\$) ----->				<----- (as %) ----->		
1976	10	90	-	100	10	90	-
1977	57	130	2	185	31	70	4
1978	95	156	5	246	39	63	5
1979	164	398	15	547	30	73	9
1980	135	344	26	453	30	76	19
1981	178	325	32	471	38	69	7
1982	158	97	61	194	81	50	39
1983	119	21	36	104	114	20	30
1984	143	135	22	256	56	53	15
1985	184	150	25	309	60	49	14

Source: American Machinist (compiled from various issues).

Korea does export machine tools and the quantity exported has indeed increased in recent years. However, Korea's machine tool industry, unlike many other sectors of industrial activity, is principally directed towards its own domestic market. In 1982 and 1983, exports were much higher than in other years as domestic demand was very low, forcing many producers to more actively market their products abroad. However, domestic consumption subsequently revived and manufacturers reverted to this market. The majority of the machine tools exported in 1984 were conventional: 40% were conventional lathes and milling machines; 32% were drilling, grinding, and hobbing machines. The remaining 28% were CNC lathes, milling machines, and machining centres. Early machine tool exports mainly went to other industrialising or developing countries. However, from the early 1980s, manufacturers have also exported to industrialising countries and this is becoming their most important export

destination: in 1983 and 1984, 60% and 80% respectively of exports went to industrialised countries. The major destinations for these exported machines were the US and Japan, which in 1984 took 36% and 26% respectively of the total value of exported machines, while Canada and Europe were also important markets (Machine Tool, 9, 1985: 125). The Korean machines exported have low unit values. For example., in early 1985, the average unit value of CNC lathe exports was US\$13,500 and of exported machining centres US\$53,000 (Monthly Foreign Trade Statistics, April, 1985). These are very low in comparison to the average unit values of the same types of machine exported by Japan (see below), but similar to Taiwan's, which on the whole is a low value exporter, although Taiwan's exported CNC lathes have a significantly higher unit value than Korea's.¹⁰

The proportion of domestic consumption met by imports has declined from 90% in 1976 to 49% in 1985, as domestic production has been able to supply a larger share of internal demand. Although indigenous production has increased rapidly, a high proportion of Korea's internal demand for machine tools is still met by imports. Most imported machine tools come from Japan, and other major supplying countries include West Germany and the US.¹¹ Imported machinery is principally either very large, very complex, or of high precision, and, consequently, of high unit value. In 1984, the average unit value of machining centres and lathes imported by Korea from Japan was US\$205,000 and US\$74,440 respectively. These average unit values were significantly larger than the average unit value of Japan's total exports of these machines, which were US\$95,000 and US\$62,000 respectively in the same year.¹²

The major Korean consumers of machine tools are the vehicle and defence industries, together with their associated components producers. The vehicle industry alone accounts for about 30% of total machine tool consumption (Metalworking, Nov. 1986: 148-49). The plastics industry is also a significant consumer of machining centres, mills and EDMs for the production of moulds and dies. As the Korean machine tool industry is orientated towards supplying other domestic industries, the expansion and technological development of its large consumers affects the size of the

market for Korean producers and influences the production strategies of firms within the industry. The growth of the defence and vehicle industries, and their links with the machine tool industry, are discussed in detail below. Chapter 2 noted the dependence of CNC machine tools on microelectronics components. The following section assesses the possible entry of the Korean electronics industry into this production area.

5.4.2 The Defence Industry

The strategic thinking behind the government's encouragement of heavy industry in general in the early 1970s stressed its potential to support the defence effort, especially in view of the perceived threat posed by the reduction of US forces in Korea. Nevertheless, that thinking was revealed as a failure by the late 1970s, and its consequences for the whole of Korean industry were quickly appreciated by government and other analysts. For example, Rhee et al. argue that "underlying this failure was the adoption of a second principal policy objective - greater self-sufficiency in meeting the country's defence needs - to be added to the first objective of export-led economic development", and "the adoption of this second principal policy objective ... naturally weakened the previous singular objective" (1984: 67-68). As well as promoting the development of military-related industry, the government was, of course, also its major customer.

In the late 1960s, Korea's defence industry was limited to a small number of government arsenals manufacturing simple munitions. The rapid development of defence production in the 1970s was undertaken primarily by private companies. However, their development in this sector was funded by government subsidies and, consequently, they were insulated from normal commercial pressures. The distribution of these subsidies between firms was to a large extent a political decision, frequently made through personal contact between President Park and the chairmen of the various *chaebol*. The funds were used to import expensive equipment which was often of far greater capacity than could be effectively utilised. Funds from defence contracts were also used by firms to subsidise their

production in other non-defence-related failing industrial sectors. Companies were also given a wide range of tax incentives to enter the defence sector, the government guaranteeing them 10% annual profits. In theory, to ensure that firms did not become too dependent on defence production, the share of total firm production in defence-related activities was restricted by legislation to 30%. However, there were many cases where this limit was not strictly enforced (Nolan, 1986: 62-65, 112-15).

The efficiency of investments made during this period was low, and capacity utilisation in the machinery and equipment sectors, which included defence manufacturing, declined steadily from 67% to 53% between 1974 and 1980, while that of the whole manufacturing sector remained constant at 70% (UNIDO, 1987: 16). Other problems in the industry stemmed from very poor quality control and from a general shortage of required skilled labour. A large proportion of the product technology used was supplied by US defence contractors: helicopters were manufactured through an agreement with Hughes Aircraft; naval patrol craft were produced under US supervision; and ordnance and ammunition were made to US designs or under licence from US firms. The US government controlled the technologies that were transferred, and restricted the sale of Korean-made defence products containing US components or technology. In addition, the US denied the Korean government permission to manufacture several of the defence items it requested. As well as using US technology, President Park initiated a prestige project to develop an indigenous capability in missile technology (Nolan, 1986: 73-79).

Towards the end of the 1970s (which also marked the end of the Park régime) and in the early 1980s, the Korean government recognised that serious mistakes had been made and that the heavy industries had to be rationalised. This reorganisation included government designation of firms as sole suppliers in particular defence sectors. Other manufacturers in the sector were either forced out or became sub-contractors to the sole supplier. Furthermore, the 30% limit on defence production was to be enforced more vigorously. Much of the

excess capacity created in the mid-1970s was indeed reduced by these measures. However, into the mid-1980s several firms were still suffering from the residual effects of over-investment and had not been able to re-adjust their manufacturing activities. (The case study in Chapter 6 discusses an example of a machine tool firm (E) which is part of a large heavy engineering group that did not succeed in re-orientating its business and was later merged with a more successful *chaebol*.) Some current defence production is undertaken by firms which manufacture similar products. For example, Kia was made the sole supplier of domestically-manufactured wheeled vehicles purchased by the armed forces. Kia manufactures jeeps, trucks, and some cannon for the military, and has been able to integrate this production with its main output of small vans. The general strategy of integrating similar military and civilian production where possible should enable manufacturers to benefit from economies of scale or scope.

The links between the Korean machine tool industry and the military have closely followed the overall career patterns of military-heavy industry links. Indeed, as Amsden and Kim observed, the machinery industry did not "evolve organically" but "exploded jumbo sized on the industrial scene" (1986: 94). Yet this headlong rush into defence-related industries did not survive the economic and political crisis of the late 1970s. While the machinery sector continued to be promoted by the government, it was primarily on the basis of its potential contribution to civilian manufacturing. Although many of the machine tool producers supply defence contractors, in only a few cases do they manufacture machinery specifically for the defence sector, and even in these cases the machinery produced can be used for other purposes. For example, one *chaebol* which is a large explosives manufacturer has a division which developed small lathes used to produce timing devices. These machines are now supplied in fairly large numbers to manufacturers of toys and pens. Thus, while Korea flirted with the military-machine tool patterns characteristic of the US, these did not persist, and the present situation strongly links the machine tool industry to civilian production.

5.4.3 The Vehicle Industry

The close technological links between vehicle and machine tool industries were noted in the last chapter. The vehicle industry has become the largest single market for machine tools in Korea, and, indeed, a number of vehicle producers have themselves become machine tool manufacturers. Korea's vehicle industry has been fostered by the government since 1962, when a total ban was imposed on the importation of complete vehicles and foreign ownership in domestic vehicle-producing firms was restricted. Production in the early 1960s was at a minimal level and amounted to little more than the final assembly of imported semi-knocked-down kits.¹³ In the late 1960s, completely-knocked-down kits were being assembled by firms collaborating with foreign vehicle manufacturers, including Ford and Toyota. By 1972, vehicle production capacity in Korea was 54,000, divided between four firms. However, their combined output in that year was only 10,000 units (The Korea Herald, Auto Industry Supplement, 31 March 1985; Altshuler et al., 1984: 41-42).

In 1974, the government instituted its long-term automobile promotion plan. The major aims of this plan were: (i) to change the industry from assembling imported kits to the development of Korean models; (ii) to increase the local content of the vehicles produced; and (iii) to encourage indigenous private enterprises to invest in large-scale production in order to realise economies of scale. Responding to the government's promotion plan, three firms introduced new models: Kia introduced its Brisa in late 1974; Hyundai the Pony in 1975; and Saehan (a joint venture with General Motors) the Gemini in 1977. These main car-producing firms still maintained close links with foreign companies. For example, Kia continued to assemble both Peugeots and Fiats, as well as manufacturing the Brisa. Production continued to rise, but, as so many firms were still involved in vehicle manufacture, individual companies could not achieve economies of scale (Altshuler et al., 1984: 43). In 1979, following government moves to rationalise heavy industry, the government designated the car industry for strategic export development and undertook measures to reorganise it. Only two firms, Hyundai and Daewoo (which had taken over the Korean-General Motors joint venture),

were allowed to continue car production: Dong-A was to produce all civilian jeeps and Kia was allocated small vans and trucks; various commercial vehicles, including buses, were to be produced by Hyundai, Daewoo, Kia, Asia, and Dong-A.¹⁴

In the mid-1970s, Korea began exporting vehicles to countries with no indigenous car industries - mainly in the Middle East, Africa, and Latin America. In 1977, these three areas took over 90% of Korean car exports (Machinery Korea, April 1985: 8). In 1978, Hyundai expanded into the European market. At this time, the estimated production cost of a Hyundai Pony was US\$3,972, approximately US\$1,700 more than a similar basic Japanese car. On the export market, the Pony had to be sold for less than the equivalent Japanese car, because of customer unfamiliarity with the model and producer. Hyundai exported 19,000 Ponys in 1979, absorbing its losses with government support (Altshuler et al., 1984: 43). Declines in both the domestic and the world market further depressed the car industry. In 1981, the industry's combined losses were over US\$100 million and Hyundai, the largest car producer, was operating its factory at less than 50% capacity (The Economist, 6 March 1982: 79).

Despite huge losses in its car production, Hyundai expanded its facilities to take its total capacity to 300,000 cars per year. This was undertaken with the technical collaboration of Mitsubishi, which had acquired 10% of the company.¹⁵ In 1982, Hyundai brought out a re-styled Pony and developed two new models, the Excell and the Stellar. The engine and the axle of the Excell were designed by Mitsubishi, and the body of the car was designed in Italy. The design of the Stellar is similar to that of the Ford Granada, which Hyundai had previously produced in Korea under licence. With these new and improved models, Hyundai started to export to North America: the Pony II was first sold in Canada in 1983, followed by the two new models, and in 1986 Hyundai entered the US market. Both these markets have proved very successful for Hyundai. In 1984, the company exported 50,379 units (36% of Hyundai's total production for that year), more than two and a half times the level of the previous year, with Canada taking 64% of these exports (Company literature, 1985). In 1986, Hyundai sold a total of 168,200

vehicles in the US market. The expansion of Hyundai's total production capacity to 600,000 vehicles a year was also completed in 1986 (Garnett, 1987a). In the same year, Hyundai started to build an assembly plant in Canada, to supply the Canadian market and to export a small number to the US. This plant is to have a capacity of 100,000 units a year. The cars will have some local content, and a stamping plant may be added later. The cost of the construction of the plant has been heavily subsidised by the Canadian government (Gibbens, 1986).

The growth of Daewoo Motor Corporation, a joint venture between the Daewoo *chaebol* and General Motors, has not been as dramatic as Hyundai's. In 1985, Daewoo had one-sixth the production capacity of Hyundai (Korea Herald, 31 March 1985). The main vehicles produced were the Maepsey, a fairly old Korean-designed car, and the Royale, based on the Opel Rekord. With the technical support of General Motors, Daewoo have commenced manufacturing the Le Mans, which is to be exported to the US and sold by General Motors dealers under the Pontiac brand name. It was anticipated that by early 1988 Daewoo's annual car production capacity would be about 340,000 (Garnett, 1987a).

With the introduction of the Anti-Monopoly laws in 1985, Kia was allowed to re-enter car production. The new car produced by Kia was designed by Mazda of Japan, with whom Kia already had technical agreements covering the production of mini-buses. Mazda has an 8% holding in the company, and Ford owns a further 10% (Garnett, 1987a).¹⁶ These vehicles are to be exported to the US and sold through Ford dealers. At the same time, Dong-A, a part of the Ssangyoung Group, started negotiations with Toyota for the production of passenger vans. Samsung, a conglomerate with no history of vehicle production, is also negotiating with Chrysler for the production of cars exclusively for export. In 1989, the government plans to lift all restrictions on the number of domestic car producers, which will enable both these producers to enter production. The manufacturing tie-ups between Korean firms and foreign producers give the former many advantages. Firstly, they receive designs, production technology, and manufacturing support from the foreign company. Secondly, they have automatic access to established

dealer networks in export markets. And, thirdly, the exports of Daewoo and Kia, as manufacturers for US firms, are less likely to be limited by any US import quotas introduced to further protect the vehicle market.

Vehicle component production is also a growing sector of Korean manufacturing and is becoming a large machine tool consumer. This industry is slightly older than the car industry itself, as it started on an informal basis in the 1950s to supply cheap replacement parts for US army vehicles. The domestic demand for components and parts has increased as the car industry has expanded and as the localisation rates for vehicle production have risen. The domestic content of cars and trucks has steadily increased from 60% in the mid-1970s to over 90% in the mid-1980s. (In 1984, Hyundai claimed that its Pony had a 98% local content.) Parts which continue to be imported include special bearings, fuel injection systems, steering systems and automatic gear-boxes. (Machinery Korea, April 1985: 13).

Vehicle components are also exported. Initially, the parts which were exported were relatively minor; they used little technology in their production, but were labour intensive to make, e.g., springs and seats. Exports have become more technologically complex and the technological development of the industry has depended on the transfer of foreign technology. In 1982, there were a total of 57 technological cooperations and 17 joint ventures making vehicle components. These included the production of transmissions, engines, rubber parts, and electronic devices (King, 1986b). Three new joint ventures were set up in 1985 with major American firms (Ford, General Motors, and Chrysler) in order to supply components to the vehicle production plants of their foreign partners (Butler, 1985). Even with the expansion of the components industry, Korea still imports large quantities of car parts and components. In 1986, Korea imported vehicle and components valued at US\$730 million and special steels destined for vehicle production valued at US\$130 million (Garnett, 1987a).

The car industry in Korea has come to constitute the most important feature of the economic and technical environment for machine tool

manufacture. Indeed, the development of the CNC industry cannot be understood without reference to the vehicle sector. The car industry is the most important buyer of indigenously produced CNC machine tools; it works very closely with machine tool firms in the installation of new equipment and in the solution of production problems. Moreover, Chapter 6 will document and show some consequences of the close organisational links between machinery and vehicle makers. These links have been formed both internally (i.e., when machine tool firms and vehicle producers are part of the same conglomerate) and externally (between conglomerates and between independent firms).

5.4.4 The Electronics Industry

At present, the Korean machine tool industry is highly dependent on foreign suppliers for the electronics components used in CNC and FMS manufacture. While the Korean industrial electronics sector is still developing, when and if it matures its role will be largely that of an indigenous components supplier, supplanting foreign sources, rather than that of a major user of machine tools. The overall growth of the Korean electronics industry and its acquisition of technical capabilities have been spectacular in the twenty years from 1965 to 1985. Before 1965, the only electronics production in Korea was the assembly of simple AM radio sets. Black-and-white television sets, stereos, and radio communications equipment began to be assembled in the mid-1960s, but the local content of these products was low, all major parts and components being imported (Kim Linsu, 1980: 258). By the mid-1970s, the electronics industry had sufficiently built up its capabilities to enable it to produce colour televisions and assemble computers. This was followed in 1978 by the manufacture of microwave ovens and, in 1979, by video cassette recorders (VCRs). In 1984, 64K DRAM (Dynamic Random Access Memory) chips were produced in Korea, followed in the next year by 256K DRAM chips. Indeed, Korea was the third nation in the world, following Japan and the US, to manufacture these chips. While nearly all these advances relied on imported technical know-how, in 1987 a 256K SRAM (Static Random Access Memory) chip, which worked faster than those

manufactured in Japan, was produced in Korea by a domestic firm using its own design and production know-how (Ford, 1987).

Table 5.4 shows the growth in value of Korean electronics production and exports between 1965 and 1985. The industry is export-orientated: the proportion of exports to production has been over 50% since 1969, and Korea became a net exporter in the electronics sector from 1973. The vast majority of electronics exports are consumer electronics and electronics parts and components. A high proportion of early electronics exports originated in foreign-owned firms or joint ventures. In 1974, Korean-owned firms accounted for only 26% of electronics exports; however, their share increased to 53% by 1981. Imports consist mainly of electronics parts and components, and the import of industrial electronics is becoming steadily more important. Consumer electronics only account for a very small proportion of imports - 5% in 1982.¹⁷

Like the vehicle industry, the electronics industry was selected as one of Korea's priority industries in the First Five Year Plan in 1962. Initially, the industry was orientated towards import substitution and the government used various incentive programmes to encourage the development of the industry while barring the import of consumer electronics products. The Electronics Industry Promotion Law of 1969 was aimed at changing the industry's orientation from import substitution towards exports. Among the measures in this Act were long-term loans at low interest rates, accelerated depreciation, no import duty on production equipment, and the establishment of an overseas marketing research service (Kim Linsu, 1980: 265). Unlike the vehicle industry, the government's programmes for the electronics industry were not only for the benefit of indigenous producers. Foreign investors were also attracted by a variety of special incentives and privileges, applying only to the electronics industry (Suh Sang Chul, 1975: 109).

The electronics industry was re-emphasised in the Third Five Year Development Plan (1972-1976). A special industrial estate for the production of electronics goods was built at Gumi, and many delegations were sent abroad to attract further foreign investment and know-how. In

Table 5.4 Korean Electronics Production and Exports
(in million US\$)

Year	Production (P)	Exports (E)	$\frac{P}{E}$ E (as a percentage)
1965	11	2	17
1967	37	7	18
1969	80	42	53
1971	138	89	64
1973	435	322	74
1975	860	582	68
1977	1,758	1,107	63
1979	3,280	1,845	56
1981	3,791	2,218	59
1983	5,560	2,980	54
1985	9,600 ^a	5,250 ^a	55

a. Estimate

Sources: Suh Sang Chul, 1975; 111; Chon Kilnam, 1984; 29;
Berney, 1985; 49.

1978, and again in 1979, government controls of licensing agreements were relaxed (Business International Asia/Pacific Ltd., 1979: 132). Since 1979, the government has undertaken a major campaign to upgrade electronics capabilities, and has targeted the computer and semiconductor industries. As a part of this campaign, imports of personal and mini-computers were banned, and a flat-rate tariff of 20% was placed on all imported integrated circuits (ICs). 32 jointly-funded research projects were instituted in 1982, linking the public and private sectors, and were given government subsidies. Of these projects, seven were in the electronics sector, covering a broad range of technologies: cable telecommunications, medical equipment, robotics and CNC machine tools, VCRs, digital ICs, and software. Under the Semiconductor Industry Fostering Plan (1983), the government lent domestic firms US\$346 million to further develop semiconductor production capabilities. In 1984, an additional US\$91 million was added, specifically for the development of the one megabyte chip (Berney, 1985: 48-49).

The manufacture of consumer electronics accounts for nearly 40% of electronics production in Korea and is dominated by domestic firms. Domestic production of black-and-white televisions started in the mid-1960s, using technology imported from Japan and Holland. The technology agreements included product specifications, production know-how, technical personnel, component parts, and assembly processes. In the initial phase of production, foreign experts were employed to give technical assistance in production plants, but as local personnel acquired technical capabilities in production, the use of foreign assistance declined (Kim Linsu, 1980: 259). For the initial production of more complex consumer goods in the 1970s, Korean firms continued to use foreign technology, acquired either through licensing agreements or, in the case of the electronics-producing *chaebol*, the establishment of joint-venture subsidiaries with large foreign producers. Firms also had close links with the foreign companies to which they sold their products. Westphal et al. (1984: 286) note that foreign buyers were an important source of technical help in exporting firms. Representatives of the foreign buyers, who visited the Korean installations to inspect the production facilities or to check on quality, frequently helped with

technical and production problems and recommended improvements in manufacturing. These contributions of minor innovations from export buyers to Korean firms were a major factor in increasing the product-quality and efficiency of exporting firms.

While some of the new consumer products began to be exported only after local demand had been satisfied and quality had risen to international standards, other electronics products were specifically produced in response to export demand. For example, colour televisions were first produced in 1974, but colour television broadcasting did not begin in Korea until 1980 (Park Ungsuh, 1984: 9). Other products developed in this way included electronic calculators, tape recorders, and electronic digital watches (Kim Linsu, 1980: 266). Most exported consumer products were sold directly to foreign industrial buyers, who distributed and sold the products under their own name or trademark. This pattern was broken by Samsung in 1985, the first Korean electronics producer to start selling its consumer products in the US and Europe under its own name.

The production of parts and components is now the largest sector in the electronics industry. It is also the sector in which foreign firms have most influence; combined, foreign firms and joint ventures account for over half of production. When electronics production first began, all major parts and components were imported, with only simple electrical parts, such as resistors and capacitors, being supplied by domestic producers. Localisation rates have gradually increased with the development of the components sector. However, the components which still have to be imported are often those most critical for the operation of the final product.¹⁸

One area of the parts and components sector which deserves special attention is the production of discrete semiconductors. The initial development of this field in the early 1970s came from investment by foreign firms, mainly trans-national corporations (TNCs), in transistor production and IC assembly.¹⁹ By 1973, there were 27 US and 56 Japanese electronics ventures in Korea. TNCs which set up subsidiaries included Tokyo Sanyo, Toshiba, Motorola, and Fairchild. The products covered in

the production range varied from transistors to wafer fabrication and IC assembly. The influx of these foreign firms changed the orientation of the components industry from import substitution to exports. Of the electronics components produced in Korea, approximately three-quarters are now exported - either as components for foreign buyers, or in Korean-assembled electronics products. For ICs the proportion is even higher: in 1974, 89% of ICs produced were exported, and by 1981 nearly 100% were exported. The largest markets for these products are Japan and the US (UNCTC, 1983: 352). The raw materials required for semiconductor production - silicon ingots, fine-grade chemicals, and very pure metals - all have to be imported.

The character of semiconductor production in Korea has changed from its original state as an off-shore production centre dominated by large foreign electronics companies. Rising wages and the increase in capital intensity in production equipment have made the country less competitive as an off-shore location for TNCs, so few new foreign firms have been established in Korea since the mid-1970s. However, production capacity has been expanded by domestically-owned firms which have begun manufacturing ICs and discrete semiconductors. The main buyer of these parts is the burgeoning consumer electronics sector - often producers within the same *chaebol*. These indigenous electronics firms entered microelectronics production using a variety of technical agreements, and by setting up joint ventures mainly with Japanese and US firms. The depth of knowledge supplied in these agreements varied to a great extent: some consisted solely of the supply of manufacturing equipment, while others included the detailed training of Korean personnel in design skills; and some agreements were comprehensive, covering all technology from process technology and chip design through to production and maintenance.

Some Korean producers have either acquired or established design and production centres in California. In Santa Clara alone, three Korean subsidiaries have been established: Samsung has a subsidiary producing 5" 64K DRAMs using an American design; Hyundai also has a plant manufacturing 5" wafers; and Daewoo's subsidiary is making private branch

exchanges and optical fibre systems, under licensing and marketing agreements with Northern Telecom. And Goldstar has invested US\$60 million in a custom IC centre in nearby Sunnyvale. Daewoo had originally planned to produce semiconductors as well, but this project was dropped because of high capital costs. Along with these four privately-sponsored ventures, the government-supported Korean Institute of Electronics Technology has a liaison office in Sunnyvale, to oversee local developments (Berney, 1985). While some consumer electronics firms have established overseas plants using technology that was already established in Korea, all these ventures have been set up in order to acquire new microelectronics technology. The results of such technical acquisitions, in the form of new chips, will later be mass-produced in Korea and used in Korean products.

Industrial electronics is the least developed Korean electronics sector and accounts for less than 20% of electronics production. The majority of domestic production is currently centred on telecommunications equipment. In this area, as elsewhere, the role of technology agreements has been important, and the government has regulated them to ensure compatibility with the existing network. Computers are the other main product in the industrial electronics field. Computers were first assembled in Korea in 1976, and their production has been increasing rapidly. Fujitsu, IBM, and Sperry have 100%-owned local firms operating in Korea. Korean companies have technology cooperation arrangements with firms such as Hitachi, NEC, Olivetti, AT&T, Digital Equipment, Honeywell, Prime, and Hewlett Packard. Most of the agreements with American firms are in the form of joint ventures. Often, the agreements include the export of computer hardware peripherals (e.g., terminals) and more simple systems, such as personal computers, to the foreign supplier. Mainframe computers are also produced in the joint venture firms, for sale only on the domestic market. Industrial consumption in this sector relies heavily on imports; in 1982, imported goods accounted for over 60% of this market (Chon Kilnam, 1984: 29).

The main reason for the lack of development in this area is that industrial electronics relies to a great extent on the use of customised

chips. The manufacture of these chips is both expensive and difficult, requiring a high level of design capabilities. One of the aims of the large companies in setting up research, development and production facilities in California is to build up the appropriate skills. Semi-customised chips, which enable the design and production of industrial electronics chips to be standardised to a greater extent, are being introduced by Japanese firms. The customisation of these chips, tailoring the chip to its specific function, is encapsulated within the software. Korean firms do not yet have the capabilities to manufacture these chips, but when such chips are locally produced the barriers to entry into industrial electronics production may be lowered, and may, in turn, enable the Korean electronics industry to build up its industrial electronics sector more easily.

The highly successful Japanese CNC industry is characterised by close working relationships between makers of control units and machine tool producers. By contrast, Korea has not yet successfully entered controls production, and reliance upon Japanese control units is almost total. Nevertheless, there have been various attempts in Korea to manufacture controls for CNC machines, but these have so far been very basic in comparison to Japanese versions. If Korea is ever effectively to enter controls production, the technological capabilities of its microelectronics sector will have to be much further developed. In particular, the design skills involved in the development of customised and semi-customised chips will have to be acquired. The Californian enterprises represent a substantial and serious effort at developing this sector. Moreover, microelectronics skills are heavily used in FMS design and installation. Both FMS and control unit design also make demands upon software capabilities, and, while Korea is currently attempting to encourage its software industry, progress has been limited. On current evidence, it is unlikely that Korean firms will replace foreign suppliers of sophisticated and complex microelectronics components within the next decade. However, the capabilities required to make less complex electronics components are already in place in Korea and their production is being encouraged, particularly by the Korean Machine Tool Manufacturers Association (KOMMA).

5.5 The Chaebol

The development of Korea's heavy industry in general cannot be adequately understood without reference to the country's special form of business structure. For a relatively small country, and one whose industrial development is of recent origin, Korea has a surprising number of very large conglomerate companies — known as *chaebol*. Fortune's 500 (the 500 largest companies outside the US) for 1985 contained ten Korean companies, two of which (Hyundai and Samsung) are also among the 50 largest companies in the world (including the US). In 1985, these two companies each had sales of over US\$14 billion and over 100,000 employees (Fortune International, 4 Aug. 1986: 173). Another sixteen NICs and developing countries also had companies in the Fortune 500, and in total they accounted for 34 companies in the 1985 listing. Yet, unlike the Korean companies, many of these other NIC and developing country companies were petroleum producers/refiners or mining companies, and few were involved in manufacturing. By contrast, nine of the ten Korean firms were mainly manufacturing businesses.²⁰

The *chaebol* organisational form partly reflects the history of its development. At the centre of each *chaebol* is a chairman, who is sometimes the founder of the group and the leader of its expansion. In older *chaebol*, this role may have been taken over by direct descendents of the original founder. As the group develops, it becomes more family-based, with successfully established companies being passed on to other members of the founder's family as the founder himself moves on to new projects.²¹ However, this spread of family control has in more recent years been declining, as groups have increasingly formed holding companies and employed professional managers. Indeed, government has actively encouraged the reduction of single family influence. While family control has been eroded, the hierarchical structure which evolved as an outcome of family control patterns persists.

Each *chaebol* produces a vast range of goods. For example, Hyundai and Daewoo make products from very large crude oil carrying ships to microchips. To some extent, all *chaebol* specialise in one area of the

market. For example, Samsung manufactures mainly consumer goods, while Hyundai makes mainly producers' goods. Given the sheer size of these groups, there is not only a high concentration ratio in specific industries but also a high level of business concentration.²² In 1982, the top 30 *chaebol* employed nearly 30% of all Korea's manufacturing workforce, and accounted for 40% of all sales in the manufacturing sector. The top five alone accounted for over 8% of the workforce and 23% of sales (Korean Business Review, Jan. 1987: 38). Nevertheless, there are areas of Korean industry which are relatively uninfluenced by the *chaebol* structure. Thus, in certain areas of manufacturing industry (e.g., textiles, paper and printing, and the food industry), there is little *chaebol* activity. And in all areas of industry, except those which demand very large investments, such as shipbuilding and large construction, there are also a number of small and medium independent firms (Jones, 1980: 43).²³

Not only do the *chaebol* manufacture a very large range of goods, but they are also highly vertically integrated. This is particularly visible in the electronics industry. Since there has been a general lack of small local suppliers and sub-contractors to make complex parts, the *chaebol* have established their own subsidiaries to manufacture these items. For example, Samsung Electronics Co. is a grouping of five subsidiaries of the Samsung *chaebol* situated close to each other on the same industrial estate. Samsung Electronics' main products are consumer goods - televisions, VCRs, computer peripherals, desk calculators, refrigerators, and air conditioners. In order to manufacture the glass tubes used in their televisions, a joint venture with Corning was established. The tubes manufactured by Samsung-Corning are then transported to Samsung Electron Devices, another subsidiary of Samsung Electronics Co., through an underground tunnel linking the two firms. Here they are fitted with electron guns and then sent to Samsung Electronics Co. as fully assembled picture tubes. Samsung Electronics Parts, another member of the group, manufactures several of the other critical television components. Thus, the output of one subsidiary is an input for manufacturing in other subsidiaries. Similarly, in Hyundai's vehicle production, 45% of vehicle parts are made on the same site on

which vehicle assembly takes place, and, in total, 75% of parts are sourced within the Hyundai group (Housego, 1988: viii).

The *chaebol* also have their own R&D facilities. Of the 130 industrial research laboratories registered in Korea in 1984, 115 were parts of the various *chaebol* and the rest had been established by medium-sized independent firms (KIRI, 1985). In the machinery sector, of the 23 industrial laboratories, only one was part of an independent firm. The electronics manufacturers have always led in the establishment of research facilities. Goldstar, an electronics manufacturing *chaebol*, established the first privately-run research laboratory in Korea in 1975, and has subsequently opened another nine. In June 1987, it opened the largest private research institute in Korea, employing 820 people. The work of this institute is divided into four areas: basic research for the development of new materials and systems, consumer products, office automation, and the design and pilot production of various semiconductors (Korean Business Review, June 1987: 49). Samsung established its research centre in 1979 and also operates its own technical graduate school. The main vehicle producers also have large and active research facilities and training centres. For example, Hyundai's main vehicle research centre employs 1,500 people and a further 300 are employed in a separate engine development centre (Housego, 1988: viii). In many cases, the *chaebol* research facilities are far in advance of those run by the state. The significance and general pattern of *chaebol* research efforts for innovation in its component firms is enormous. Individual firms in the conglomerate have access to a concentration of R&D capabilities which would be extremely difficult for an independent firm to develop.

A Structural Problem?

The most rapid period of *chaebol* growth took place in the early 1970s. In 1973, the largest 46 groups accounted for 15% of non-agricultural GDP; by 1975, they accounted for 19%. A significant proportion of this increase originated in the top five *chaebol*, whose share of non-agricultural GDP rose from 5% to 7% in the same period (Jones and Sakong, 1980: 268). The expansion of these conglomerates has

at various times been considered to be a problem by government, some businessmen, and independent analysts. Firstly, the efficiency and integrity of market processes were called into question, mainly by businessmen in smaller firms. It was argued in the late 1970s that the *chaebol* not only had opportunities to become monopolistic in specific markets, but that they might also behave "less competitively" with each other because of fear of reprisals in the same or other markets. Individual *chaebol* could also use cross-subsidisation within the group to undercut independent firms which were either its suppliers or its competitors (Jones, 1980: 124-25, 147-48). Secondly, the development of small and medium firms was thought to have been retarded because they were given less government support than the *chaebol*. Industrial analysts suggested that this slow development of smaller firms meant that an adequate sub-contracting network had not been established, and, because specialisation was not viable for small firms, they argued that this sector might never develop (Amsden and Kim, 1986: 118).

These arguments often pointed to the absorption by the *chaebol* of a disproportionately large share of the subsidised credit allocated in the 1970s, leading to allegations that the government and conglomerates were in league, at the expense of smaller firms. (Difficulties in obtaining credit forced smaller firms to procure financing from an illegal, and more expensive, "kerb market", putting them at a further disadvantage compared to the conglomerates.) It was frequently suggested that the government favoured the *chaebol* in the allocation of funds because of their political donations (see, for example, Nolan, 1986: 65). Jones and Sakong (1980: Ch. 8) suggest that this may indeed have been the case during the Rhee régime in the 1950s, when a significant proportion of *chaebol* growth originated from privileged access to government-controlled markets. However, they contend that while the *chaebol* continued to receive some special benefits under the Park régime (1961-1979), these were less important to their growth in comparison to the expansion of productive activity. In the main, *chaebol* expansion during this period was due to their establishment of new production facilities and the creation of new subsidiaries. Jones and Sakong argue that in the 1970s the government's commitment to growth meant that credit was largely allocated to those

companies which already had a record of successful expansion, and these tended to be the *chaebol*.

In the mid-1970s, the government introduced measures to try to check the unbalanced growth of the *chaebol*. These concentrated on forcing the large groups to go public. Groups which were financially unstable were directed to improve their financial structure before going public and were barred from allocations of foreign loans. In addition, *chaebol* firms with severe financial problems were allowed to collapse or their failing subsidiaries were reorganised under other, more successful, *chaebol*.²⁴ Policy measures were also introduced to combat the lack of development in smaller independent firms. The Small and Medium Industry Promotion Law was introduced in 1978 and through the 1980s the development of these firms continued to be particularly promoted by government. And under the Fifth Five Year Plan (1982-1986) industrial units affiliated to the *chaebol* were encouraged to separate and become independent firms (Government of the Republic of Korea, 1983: 43). One effect of this promotion appears to have been the build up of small sub-contractors around the *chaebol*. For example, Samsung Electronics Co. has built up a network of about 200 small and medium firms to supply parts and undertake service work. Samsung has given these firms long-term contracts and discusses future needs with them (Park Ungsuh, 1984: 23).

Was the rapid build up of the *chaebol* a problem in Korea's development? Or was it the most efficient mechanism of expanding industry and rapidly acquiring technological capabilities? The very existence of the *chaebol* may have promoted faster industrial and technical development, as they enjoyed many advantages compared to other firms. Firstly, they could easily transfer management skills, of which Korea had a shortage, around the group. Similarly, technical skills, including those in repairs and maintenance, could be transferred between producers in related areas within the group. Secondly, they could more easily establish overseas offices from which they could trade and through which they could also collect marketing and technical information for product developments. Thirdly, they were able to negotiate more effectively with foreign technology suppliers for the import of new

technology. And, fourthly, they had the resources to establish their own training schemes, colleges and R&D centres to promote the technical education of their workforces. The question of the role and influence of the *chaebol* in Korean development is, therefore, a complex one, and one which will be further examined in the case study where the development of both *chaebol* and non-*chaebol* firms is considered.

The *Chaebol* and the Machine Tool Industry

In certain aspects of its structure, the Korean machine tool industry resembles that of many Western countries. There are a large number of independent, mainly small, firms and a relatively small number of large (typically *chaebol*) producers. Nevertheless, the overall significance of *chaebol* firms is very large, especially in the CNC sector. Of the 46 machine tool manufacturers considered as "relevant producers" by the Ministry of Commerce and Industry in 1977, only seven had more than 200 employees and the majority of firms had between 50 and 100 employees (Bendix et al., 1978: 28). By the early 1980s, KOMMA, to which all the main machine tool producers belong, had a membership of 80 firms, of which 57 were producers of machine tools, and the remaining 33 manufacturers of tooling, machinery components, and cast iron. The majority of the new entrants to the production of machine tools were *chaebol* members. In the late 1970s, nine *chaebol* commenced machine tool and component production, of which seven entered the metal working machine tool industry. Most of these conglomerates entered by establishing their own production facilities, and there is only one instance of a *chaebol* taking over an existing machine tool producer.

Entry by the *chaebol* means that there are now two distinct types of machine tool producers in Korea: *chaebol* firms and the small and medium independent producers. *Chaebol* producers have become a dominant force in the industry, accounting for a very large proportion of production and for much of the industry's growth in the late 1970s and early 1980s. In 1984, production by the nine *chaebol* accounted for over a third (by value) of all machine tool and component production. Table 5.5 shows the proportion of total production accounted for by *chaebol* in several

sectors of the metal cutting machine tool industry. While *chaebols* are important in conventional machine tool production, their dominance is even more marked in the CNC sector. In the case of machining centres, four *chaebol* producers account for nearly the whole of Korean output. Moreover, the entry of the *chaebol* has made the industry more concentrated. In the export of machine tools, the *chaebol* also dominate, in 1984 accounting for 53% of total Korean exports (Machine Tool, 9, 1985: 126). The *chaebol* have, therefore, in a very short time become an important and characteristic feature of the Korean machine tool industry.

Table 5.5 Total Production of Metal Cutting Machine Tools in Korea in 1984 and Proportion of Production by the *Chaebol*.

Machine Sector	Total Production (in million won)	Proportion Manufactured by <i>Chaebol</i> Firms (%)
Lathes	36,682	40
Milling Machines	15,089	38
Drilling Machines	4,795	59
CNC Lathes	9,616	70
CNC Mills	2,906	23
Machining Centres	7,497	98

Source: Adapted from data in Machine Tool, 9, 1985: 114-21

It would, however, be a mistake to suppose that the entry of the *chaebol* has pushed independent Korean producers into insignificance. In the production of most types of conventional machine tools, independent producers still manufacture a greater proportion than the *chaebol*. The low percentage of *chaebol* production of CNC mills indicates that there are several independent producers which have successfully entered this sector. And even with the entry of the *chaebol*, the largest machine tool producer in Korea is an old (by Korean standards) independent firm.

5.6 Technological Development

The foundation of Korea's acquisition of capabilities in technology-intensive industries has been the import of new technologies from industrialised countries. In the main, this technology has been directly imported by Korean firms and not brought in by foreign firms establishing subsidiaries in Korea (Enos and Park, 1988: 39; Westphal et al., 1984b: 292). A major exception to this was the manufacture of discrete electronics components which was initially dominated by direct foreign investment ventures. Even in this sector the major expansion in domestically owned manufacturing facilities in the late 1970s and early 1980s was undertaken through formal technology agreements. However, although the use of imported technology has been widespread, Korean industry has not become dependent on such imports and has successfully commenced developing its own new products.

In the execution of large projects (e.g., in the iron and steel and synthetic fibre industries), Korea bought turnkey facilities or established joint ventures. Licensing agreements have also been extensively used. A key feature of Korean firms' use of these agreements has been their insistence that technology and capabilities be effectively transferred. Enos and Park's detailed analysis of the contracts used in some large-scale technology imports stresses that "the success of the absorption of the foreign technology was [dependent] upon the precise terms obtained by the government in its negotiations with foreign suppliers" (1988: 248). Government was able to control not only the contents of agreements entered into by national industries, such as steel and electric power, but, up to the late 1970s, also legislatively restricted those used by private industry. In particular, this regulation was implemented to ensure that access to new and competing technologies was not denied, and that too high a price was not being paid.

The transfer of technology was obviously a primary aim of the government in its negotiations for all agreements, as indeed it continues to be. In 1986, the Korea Electric Power Co. negotiated with twelve different international companies for the construction of new nuclear

power plants. A spokesman for the Korean company suggested that: "[t]he key feature in determining the winner is the willingness of a bidder to transfer technology. Pricing and financing are secondary" (Butler, 1986b). The Koreans have managed to achieve their aim of technology transfer through specific terms of the agreements used. In a Korean study of 603 technology agreements entered into between 1981 and 1983, it was found that in only 3.8% of the cases was technology transferred solely in the form of designs or blueprints, and that a further 4.7% took the form of visits from foreign consultants. In the remaining 91.5% of cases, the agreements included a broad range of transfer mechanisms, including the supply of blueprints and operating manuals, consultations, training and supervision (quoted in Enos and Park, 1988: 42). Frequently, the foreign firms entering agreements have been required to train Korean personnel alongside their own employees. For example, in the nuclear plant technology project, the proposed agreement incorporated a clause stating that the new reactor was to be designed jointly by the foreign contractor and its Korean counterpart, in order that technology was effectively transferred, but that the foreign company would still have to take full liability for any flaws in design (Butler, 1986b).

However, technology imports have not been limited to formal technology transfer agreements. New technologies have been acquired through the import of individual pieces of equipment. Foreign consultants have been employed to advise in Korean factories and to train personnel. In some areas, Korean firms have acquired adequate capabilities to develop and design the major part of new products, but still require some technical support from foreign firms. This has occurred, for example, in the development of new models in the vehicle industry. A different approach has been adopted by the electronics industry, which established overseas research and development facilities in California's Silicon Valley, an area where it was relatively easy to employ experts to work to the firm's requirements. Technological capabilities have also been acquired by Korean personnel educated in foreign universities and colleges, or by those who were given additional training in foreign plants. One less orthodox contribution to the build up of capabilities and improvements in manufacturing has been described by Westphal et al.

as "learning by exporting" (1984b: 286). It should be stressed that this form of learning only occurs when there is direct contact between the manufacturer and the buyer, and usually results from visits to the Korean firm by the foreign buyer to advise on production, discuss product specifications, etc. As this mechanism is dependent on the type of relationship with the foreign purchaser, and not solely on exporting, a better description of this learning mechanism might be "learning by supplying".

Chapter 2 documented three other ways in which a full range of technological capabilities is built up in industrialising countries: learning based on experience in production, learning by investing in the creation of knowledge, and learning through technological links established between users and producers (interactive learning). All these methods have also been used in Korea and have complemented their technology imports. Process technologies learnt in the manufacture of one item have been transferred to the production of other goods. Westphal et al. note that this occurred particularly in mechanical engineering industries, where skills such as casting and machining could be applied to the manufacture of many different products (1984b: 289). Furthermore, the basic capabilities learnt in production have been applied in the manufacture of new, more complex models. For example, both the electronics and vehicle industries first commenced manufacture by assembling goods, and the skills acquired in this early stage were used as a base for later developments. In addition, the product knowledge gained from assembly activities or basic manufacture helped firms select suitable partners or licensors for subsequent technological developments and to negotiate more efficiently in acquiring new technology.

Korea's commitment to R&D investment has increased rapidly: in 1980 the proportion of GNP devoted to R&D investment was 0.57% and by 1987 it was 2.2%. In comparison, in the mid-1980s approximately 3% of Japan's GNP was devoted to R&D. There are two distinct levels at which investment in technology creation takes place; firstly, the government has been active in establishing and funding technological institutes to support developing and expanding industries; and, secondly, firms, mainly within *chaebol*, have

established their own facilities. In 1987, private industry's investment in R&D was nearly three times greater than government's, a figure broadly comparable to the Japanese situation in the early 1970s. A high proportion of the work undertaken by research institutes, especially those which are privately financed, is in product development and there is little fundamental research. Nevertheless, in some industries there are high levels of development capability, even though they are focussed on very specific areas. For example, semiconductor research is concentrated in the development of new memory chips and little work on customised chips has yet been initiated. The government has also invested heavily in its educational system, and both government and individual firms have instituted vocational training schemes.

Because there has been widespread and integrated development, many firms have been able to obtain technological support from both their suppliers and their users. In particular, this has occurred within the *chaebol*, where producers and users are often under the umbrella of the same group. In these cases, there has been considerable joint development work and immediate help in problem areas in application or production has been available. Finally, the combination of firms in complementary industrial production has enabled groups to establish R&D facilities which serve all the individual firms. The increase in the use of small and medium firms as sub-contractors to the *chaebol* means that these firms are now included within the interactive process and are given considerable technical, and in some cases financial, support by the *chaebol* to which they are linked.

Although Korea has acquired significant capabilities in production, a major bottle-neck is in product and process development. Thus, while sufficient know-why has been acquired to enable plant operation and some adaptation work to be undertaken, Korea is still reliant on other countries to supply the know-how which is incorporated in new designs. In the machine tool industry, the development of such skills is crucial if it is to support its user industries. Accordingly, the following chapter considers exactly how the CNC machine tool industry has acquired technological capabilities, and, in particular, design skills.

Notes

1. See, for example, Balassa (1981); Kuznets (1977); Cole and Lyman (1971); Hong and Krueger (1975); Westphal (1978a, 1979); Westphal et al. (1981, 1984a, 1984b); Little et al. (1970).
2. The Korean usage of the term "heavy machinery and chemical industries" is very broad, comprising basic intermediate products, electrical and non-electrical machinery and transport equipment.
3. For a detailed review of the literature in this area, see Fransman (1986b).
4. For details of the Korean political context, see Henderson (1968), Harris (1986) and Hamilton (1986).
5. Whether goods manufactured for export were favoured by the government's incentive measures over those manufactured for the domestic market is not clear. Nam concludes that domestic sales were favoured over exports in the aggregate of all industries, but in the manufacturing sector, which accounted for the majority of Korea's exports, export sales were given greater incentives than domestic sales (1981: 210; also see Westphal, 1979: 238.)
6. Import Liberalisation Rate = $(T - R)/T$
 Where T = Total number of items by CCCN 4-digit
 R = Number of restricted items by CCCN 4-digit according to the Ministry of Commerce and Industry's Annual Export and Import Notice (Amsden and Kim, 1986: 115).
7. Information on KOSAMI is derived from personal interviews in 1985.
8. See Choi Hyung Sup (1983: 169-71) for a detailed list of these acts.
9. A detailed summary of the objectives and measures in this plan is in Bendix et al. (1978: 44).
10. In 1984, the average unit values of Taiwan's exported machining centres and CNC lathes were US\$43,000 and US\$37,000 respectively. Average export values are calculated from production and trade data supplied by ITRI, Taipei.
11. In 1984, 64% of machine tool imports (by value) came from Japan, 18% from West Germany, and 7% from the US (Metalworking, Nov. 1986: 148-49).
12. These average unit values of exported machines are calculated from export data for Japan in NMTBA, 1986: 200-01.
13. In 1965, the vehicle industry in Korea assembled a mere 106 passenger cars and 35 trucks (Machinery Korea, April 1985: 4).

14. Daewoo took over the management of Saehan in 1978, and the company was renamed Daewoo Motor Co. Ltd. in 1983 (Korea Herald, 31 March 1985).
15. In 1985, Mitsubishi Corporation and Mitsubishi Motors Corporation increased their holdings in Hyundai to give them a combined 15% share of the company (Korea Herald, 31 March 1985).
16. Ford also holds 25% of Mazda (Financial Times, 11 July 1986).
17. All figures in this paragraph are derived from data given in Chon Kilnam (1984).
18. For example, the precision recording heads used in VCRs are imported from Japan, and, in the case of microwave ovens, the critical component, the magnetron, has been imported from the US.
19. TNCs invested US\$10 million in transistor production in Korea in 1971 and 1972, and other foreign firms invested just over US\$3 million in IC assembly (UNCTC, 1983: 352).
20. Similarly, in the 1985 South 600 (the top 600 companies in the Third World) Korea had the largest number of companies (93) (South, Aug. 1986: 65).
21. The Korean *chaebol* are similar in form to the Japanese *zaibatsu*, and are represented by the same *kanji* (Chinese) characters. The *zaibatsu* of the Meiji era had at their centre a chairman who was the main force behind the group. The chairman would hold a majority of the shares, and members of his family would usually hold the remaining shares. In post-War Japan, the major *zaibatsu* were broken up. They have reformed as groups of companies clustered around one or two core banks: these new groups are known as the *keiretsu* (Jones and Sakong, 1980: 259). A more detailed comparison of the *chaebol* and the *keiretsu* is in Chapter 7.
22. Concentration ratio is defined as the percentage of total industry sales (or capacity or employment or value added or physical output) contributed by the largest few firms (usually the top four), ranked in order of market shares (Scherer, 1980: 56). Jones and Sakong define business concentration as "the share of a given number of affiliated enterprises in all markets" (1980: 258).
23. For a detailed description of some of the small Korean work-shops and factories, see Brandt (1980).
24. For example, the Shinjin Group, which had been slow to change its activities in the 1970s, was decimated by the government's measures (Jones and Sakong, 1980: 127-31). In 1985, the failing Kukje Group was forced into liquidation and was not rescued by the government. And in 1986 the government forced through a series of mergers of failing subsidiaries, many of which were in the heavy industries.

CHAPTER SIX

The Acquisition of Technological Capabilities in the Korean CNC Machine Tool Industry

6.1 Introduction

The early development of the Korean CNC machine tool industry manifested many of the same processes, and proceeded in many of the same structures, as Korean manufacturing industry in general. Indeed, the introduction of CNC marked a particular response by machine tool producers to changing market requirements within Korea. By the late 1970s, Korean manufacturing industry, and especially the rapidly expanding vehicle sector, was beginning to import significant numbers of CNC machines, largely from Japan. First, a large independent firm, and then several of the *chaebol* companies, sensed domestic market opportunities in entering CNC production themselves.

The Korean enterprise may already be regarded as a considerable success. Indigenous CNC tools are now very widely used by Korean manufacturing industry and Korea has begun to export these products. Nevertheless, the learning process is still incomplete. Korean firms have not as yet acquired the full range of capabilities required for the design and development of certain types of machines, nor has control technology been mastered. Thus, the study of the acquisition of technological capabilities in this area is an assessment of skills-in-the-making. And, accordingly, it offers the analyst opportunities to witness and document the exact learning processes actually used in acquiring technological capabilities, including those that fail. This chapter analyses how the technological capability requirements for that entry were acquired during the late 1970s and early 1980s by a range of Korean machine tool makers.

Chapter 3 advanced the argument that one could not properly understand the relative difficulties of acquiring different capabilities without a detailed knowledge of the technology concerned. That argument is further developed here. Technical complexity has counted as a major

obstacle to the acquisition of design skills in the CNC field. Thus, while many producers have mastered the design of CNC lathes, the greater complexity of machining centres has so far been incompletely absorbed. Chapter 2 summarised current views concerning various learning methods, their cost and their efficiency. The present chapter surveys these methods in practice. Which learning methods have Korean CNC producers favoured, and with what consequences? Special attention is paid here to the role of what has earlier been called "interactive learning", as well as the transfer of skills by informal and tacit methods, including the movement of personnel between producers in different countries. The role of Korean structures in enabling interactive learning to occur is particularly considered.

The material in this chapter was the result of extensive fieldwork conducted in Korea by the author during early 1985. (The detailed methodology of the fieldwork, including the questionnaire submitted to sample firms, forms Appendix 1.) The study focussed upon a sample of nine firms engaged in conventional and CNC machine tool manufacture.¹ In accord with generally accepted practice in this area (e.g., Jacobsson, 1986; Fransman, 1986c), firms are identified by code, in this case by letter: A, B, ... I. These nine were the only firms in Korea which had entered the production of CNC machine tools by 1985, and, therefore, they then accounted for the entire national manufacturing capability for CNC machine tools. The sample firms also represented a very significant proportion of Korea's total machine tool production and exports. In 1984, they accounted for 47% of total Korean machine tool production and 64% of total Korean exports (see Tables 6.2 and 6.3). Both independent and *chaebol* firms were represented in the sample: five firms were members of *chaebol* while the rest were independent. Data were obtained from these firms by interview and by questionnaire. Extensive supplementary interviews were also conducted with academics and staff at research institutes, industry associations, machine tool users, and non-CNC machine tool producers. The situation described here is that obtaining in mid-1985; subsequent developments are summarised in Appendix 2.

6.2 Origins and Status of the Sample Firms

Chapter 3 noted the symbiotic nature of the transfer of skills and knowledge between the machine tool industry and the general mechanical engineering industry. By considering the origins of the firms, an estimate of their base level of technological capabilities and skills on entering the machine tool industry can be made. Which of these skills were transferrable from the firms' original production activity to machine tool production, and which did firms have to acquire? This section covers the early development of the sample firms and their present status in the Korean machine tool industry. It discusses the background of the nine CNC machine tool producers, their original product area, the time at which they started to produce both conventional and CNC machine tools, and their present range of machine tool production.

Also considered are the growth of their machine tool output, other production activities in the firm, and their reliance on the production of machine tools. Data are then presented on the firms' production levels, the proportion of their production in CNC manufacture, and their principal markets (both domestic and foreign). This provides some comparison of the relative sizes of the different firms, and their importance as part of the Korean machine tool industry. Further, it can be established whether the production of CNC machine tools has become an integral part of each firm's manufacturing activities or whether it is still only a minor element of their total output. The relationship between firms and the government is also examined, and particular attention is paid to the direct benefits firms have received from government's various incentive measures.

For the *chaebol* firms, additional information on the links between machine tool production and manufacturing activities in other areas, and the importance of the *chaebol's* own internal market, are considered. There are two distinct types of entrants among the *chaebol* firms, firstly, those which commenced manufacturing machine tools for the general market, and, secondly, those which integrated backwards into machine tool production in order to manufacture their own production equipment. The

technical development and product strategies of both these types of firm are heavily influenced by the sectors of industry which form the major part of their domestic market. In the first type, the main consideration for the producer is to be competitive on the domestic, and later on the export, market and to expand its level of production. In the second type the chief aim of entering is to improve the main company's production facilities, including its operation, in the manufacture of its main product. Market forces and competitiveness in the manufacture of machine tools are therefore more important influences on the strategy of the first type of firm than on the second.

Firm A

Firm A is part of one of the largest *chaebol* in Korea. The group as a whole employed over 150,000 people and had total sales of over US\$14 billion in 1985, in which year the group was listed among the top 25 in Fortune's International 500 (the largest 500 companies outside the US), and among the top 50 companies in the world (Fortune International, 4 Aug. 1986: 165-91). The group originated as a construction company in 1947, and has expanded to comprise 31 companies with a diversified product range. The group's present manufacturing activities include shipbuilding, large construction projects, vehicle and rolling stock production, and electronics.

In late 1967, a company was established within the group to produce passenger cars, buses and trucks. This company is now one of the largest in the group. Machine tool production started in 1978 and is undertaken within the same company that manufactures vehicles. Production facilities for machine tool manufacture are on the same large site which also includes the main vehicle production facilities. The links between car and machine tool production in this firm are extremely close, and the largest consumer of the machines produced is the vehicle division itself. The director of the vehicle division's planning department commented that his company had followed the example of many Japanese car producers. He noted that most Japanese car producers manufacture machine tools and have found that a machine tool capability within the firm made a valuable

contribution to the maintenance and improvement of their vehicle production plant. Accordingly, his firm had followed that example and built up its own capabilities in machinery design and production, though the physical proximity of the two elements is not a particularly Japanese feature. Since entering the machine tool industry, the firm's output of machine tools has grown rapidly; between 1981 and 1984 sales of machine tools increased over four times by value, and more than doubled by volume. Nevertheless, machine tool sales formed only a very small part, less than 1%, of the vehicle division's annual turnover of 750 billion won in 1984.

The range of machine tools produced is directly aimed at the needs of the car industry. The firm produces transfer machinery, multi-spindle drilling, tapping, gear hobbing and gear shaping machines, as well as a number of special purpose machines, which produce specific car components. These special purpose machines are the most important products in its machine tool range. Production of CNC machines started in 1983 and the firm now makes two types of machining centre, one horizontal and one vertical, and for each type there are two sizes. In mid-1985, a CNC copy mill was added to the range.

Firm B

The group to which this firm belongs started as a trading company in 1968 and is one of the youngest *chaebol* in Korea. In 1985 the group was listed in the top 50 of Fortune's International 500, with annual sales of nearly US\$9 billion and employing over 90,000 people (Fortune International, 4 Aug. 1986: 165-91). This *chaebol* has six major areas of business interest: trade, construction, manufacturing, leisure, shipping, and finance. In total, there are 29 companies in the group, of which 17 are in the manufacturing sector. These 17 are divided into seven fields of production: heavy machinery, automobiles, shipbuilding and plant facilities, electronics and telecommunications, chemicals, textiles, and other light industries (e.g., shoes, handbags, luggage, and sporting goods).

One of the companies in the heavy machinery division entered machine tool production in 1976, when it acquired one of the oldest independent machinery producers in Korea (a producer originally established in 1937). The firm commenced producing CNC machine tools in 1979, only three years after entering conventional production. The larger company of which Firm B is a division manufactures diesel engines, construction equipment, fork-lift trucks, and rolling stock. The company's major production facilities are situated in Inchon, where the *chaebol's* vehicle producing company is also located. Machine tool production takes place at a factory on the Changwon Machinery Complex, approximately 300 miles away, where some work on the manufacture of aircraft parts is also done. Between 1975 and 1984, the heavy machinery company invested more than US\$400 million in its production facilities, of which US\$44 million was for the facilities and machinery used in the production of machine tools (Kang Youngkook, 1984: 4; Jacobsson, 1986: 185). In 1985, machine tools accounted for 5% of the division's total turnover.

The product range of Firm B includes conventional and CNC lathes, grinding machines, milling machines, and machining centres. Out of the nine firms in the study, Firm B has the most comprehensive series of CNC lathes, producing five different types, four based on the same design but with variations in the specification: one of these models has a slant bed rather than a flat bed. The fifth lathe is much larger and of a different, and more basic, design. This company also produces horizontal and vertical machining centres, with two different sizes in each type.

Machine tool sales by the firm increased from 10 billion won in 1981 to over 15 billion won in 1984. During this period, unit output decreased slightly from 900 machines in 1981 to 855 in 1984. However, the number of CNC machines produced increased considerably, from 78 units in 1981 to 164 units in 1984. The total unit output decreased for two reasons. Firstly, the firm moved into the production of higher value machines, and, secondly, the production of some conventional machine tools was subcontracted out to several small independent Korean machine tool producers. Initially, the company only subcontracted component

manufacturing and sub-assembly work, but it now subcontracts the production of entire conventional machines.

Firm C

This *chaebol* firm was originally established in 1959 to produce rifles and other armaments, and it is still a major defence producer. The firm is now part of a much larger group with interests in chemicals, construction materials, ceramics, and food and drink products. This group is different from the other *chaebol* as it is part of an international religious organisation, the Reunification Church (the so-called Moonies). Firm C completely bought out a West German thread milling machine producer in 1982, and acquired a 75% holding of a leading German lathe producer in 1985. This ownership of foreign companies also distinguishes the firm from others in the sample and from most Korean firms. The group is fairly small by Korean standards and does not undertake any heavy engineering production work. While defence work, principally in small-arms manufacture, remains a large component of this company's output, it has become a major supplier of car components, both to the domestic and export markets, and it is expanding its production in this field. Machine tool production is based at the Changwon Machinery Complex, along with several other engineering plants in the *chaebol*. In 1984, 16% of the machinery division's turnover was derived from sales of metal cutting machine tools. Machine tool sales by the firm amounted to approximately 15 billion won in 1983 and 17 billion won in 1984.

Firm C started to make machine tools in 1976, producing its first CNC machine tool in 1980. Its range of machine tool production is very wide, with a total of about 90 different types and variations, welding machinery being the most important product area in terms of sales. The range of CNC machine tools produced includes three sizes of vertical machining centre (two of the same design), two sizes of horizontal machining centre, a CNC lathe, and a CNC milling machine. In 1985, the company was developing CNC gear hobbing, shaping, and shaving machines. Many of the production machines used in this firm and its associated divisions were manufactured in-house. However, because of the large

scale of machine tool output by this firm, the internal market did not represent a very significant portion of its sales.

Firm D

This firm started bicycle production in 1944, and its main product areas are now small vans, trucks, vehicle components, and defence equipment such as artillery and military vehicles. Like Firm C, the *chaebol* to which this firm belongs is fairly small by Korean standards. The company entered car production in the early 1970s, but when the government reorganised vehicle production in 1979, this firm was excluded from car production and given a monopoly of small van manufacture. With the government's mid-1980s plans to de-restrict many sectors of industry, it was widely predicted that this company would eventually re-enter car production. (See Appendix 2.) A machinery company was set up as part of the group in 1976. As well as machine tools, this company produces large press machinery and special purpose machines for use in the vehicle industry. Sales of metal cutting machine tools accounted for about 10% of the machinery division's annual turnover.

In interview, it was stressed that the main business of the *chaebol* was vehicle production, and that even though the production of machinery was not a profitable area for the *chaebol*, it was maintained to support its vehicle production. The *chaebol* is also a considerable defence producer, and machinery production also supports this part of the *chaebol's* manufacturing activities. The machinery division is always consulted by other parts of the group when they want to establish new process or production facilities. As part of feasibility studies of new projects, the machine tool division gives advice on the proposed new system, and, if it is capable, eventually supplies machinery and equipment for the project. About 40% of machine tool production is used within the *chaebol*. Machine tool production, however, is not based on the same site as its present vehicle production, but is situated on the Changwon Complex with some of the defence and other machinery production.

The company commenced machinery production in 1976 with special manufacturing machinery. Machine tool production began in 1977 and the first CNC machine tools were made in 1982. Machine tool sales by this firm grew rapidly from 134 units sold in 1981 to 215 units in 1983, but in 1984 unit sales declined to 163. Of the units sold in 1983 and 1984, 9 and 16 units respectively were fitted with CNC controls. As with Firm A, the range of machine tools produced includes many machines specific to vehicle and vehicle component production. General purpose machine tools produced by the firm include conventional milling machines and lathes, horizontal machining centres, a CNC milling machine, and a CNC lathe.

Firm E

This firm is part of a *chaebol* specialising in large-scale and very heavy metal working production. Its manufacturing activities encompass production of components for rolling stock (including railroad wheels and bogies), casting and forging, large-scale machining work, and building large steel structures. The group grew from a heavy industrial and forging shop founded in 1937, and is therefore one of the few groups in Korea which originated during Japanese colonisation. The group established a machinery plant at Changwon in 1975 for the production of many types of heavy equipment, and began to produce machine tools there in 1976. As a whole, the group experienced considerable financial difficulties during the late 1970s and was placed under the direct financial control of the Korea Development Bank in 1981. When the firm was visited, personnel thought that there was a high probability that several divisions of the company, including machine tool production, would be taken over by another *chaebol*. (See Appendix 2.)

In 1985, the firm was producing a range of high-speed precision lathes, including a very heavy-duty lathe, milling machines, boring machines, a CNC lathe, and two types of CNC milling machine. As most of the machinery used by the group is extremely large, very few of the machine tools manufactured by this firm are used within the group. The interviewee estimated that, since entering machine tool production, the

firm had manufactured about 2,000 machines, and of this total he thought that less than 30 had been used within the *chaebol*.

Firm F

This firm originally produced valves, other casting work, and machinery used for the production of coal briquettes. Machine tool production started in 1960, and the firm has become the largest Korean machine tool producer. While machine tools are Firm F's major area of production, with sales accounting for 95% of annual turnover, it still produces and sells some castings and gears. The origins of the firm are in Kwang Ju (S. W. Korea), and the majority of machine tool production still takes place at this plant, although it established a new production plant in the Changwon Complex in the late 1970s. In the future, the firm plans to divide production so that the Kwang Ju plant will specialise in the production of lathes and the Changwon plant in the production of milling machines and machining centres.

The firm produces a comprehensive range of both conventional and CNC machine tools. CNC production includes several different lathes, one with four-axis control, a machining centre, milling machines, and a copy milling machine. Firm F has also supplied lines of machine tools to the Korean vehicle industry. In 1981, it sold machine tools with a total value of 12 billion won, and in 1984, 18 billion won, with the majority of this growth taking place between 1983 and 1984.

Firms G, H and I

The remaining three firms are all fairly small independent firms with similar origins and outputs. Firm G, based in Taejon (Central Korea), was originally established as a foundry in the late 1940s and started to produce machine tools in 1950. Machine tools are now the firm's main product, although it still does some sub-contracted foundry work for other companies. The present range of machine tools includes conventional milling machines, lathes, and one CNC milling machine (which it started producing in 1983).

Firm H was established as a spin off from Firm G, in 1968, when the founder and present chief executive left that firm, where he was employed as a core design engineer, to start up his own business. Many of the other employees in this firm also previously worked for Firm G. In 1977, the firm moved from its original site in Taejon into a small local industrial complex. The new plant is about five times larger than the old one, and there was considerable investment, using special loans, in imported machinery for the new plant. Unfortunately, data on the increase in the value of output and sales by this firm in the 1980s are unavailable, but the firm's growth during this period is indicated by the increase in the number of employees. In 1981, Firm H had a total of 70 employees, rising to 90 in 1982, 120 in 1983, and 160 in 1984. The workforce, therefore, more than doubled during this period, and it is highly probable that output kept pace. The firm was established to produce milling machines, and this is still its major product. The production range centres around a large heavy-duty milling machine, and in 1983 the firm started to produce a CNC version of this machine. The firm has built a foundry on its new site, and, as well as casting its own beds, it undertakes some casting work for a local EDM producer.

Firm I was established in 1945 and began to produce machine tools in 1965. The firm has become a large subcontractor for Firm B, manufacturing complete conventional machine tools which are then sold by Firm B under its own brand name. Of Firm I's total production of 695 units in 1984, about 300 machines were for Firm B. The firm commenced production of a CNC lathe in 1978, and, like the other two independent firms, has not yet added to its CNC production. In conventional production, the firm manufactured lathes, shaping machines, milling machines, and some printing and paper cutting machines. Machine tools were their most important products. In 1982, the firm's annual production of machine tools amounted to 2.3 billion won; in 1983, this declined to 2.1 billion won and then rose again in 1984 to 3.7 billion won.

Discussion of Sample Firms' Development

Table 6.1 summarises the basic characteristics of the sample firms, including details of the firms' origins, the dates at which they commenced conventional and CNC machine tool production, their main machinery product sector, and, in the case of the *chaebol* firms, the major products of the company or division to which the firm is allied, and the importance to the firm of the *chaebol* internal market. This discussion analyses the firms' similarities and differences and the reasons why they entered the industry. The direct effects of the government's promotion of the industry are also treated.

Among the sample firms, a clear division can be made between recent entrants to machine tool production, all *chaebol*, and older firms, all independents. The previous chapter noted *chaebol* entry to many of the industries promoted by government during the 1970s and early 1980s. Yet the first firms to start experimenting with CNC development were two of the older independent firms: Firm F in 1977 and Firm I in 1978-79. The *chaebol* firms all commenced CNC production in the early 1980s. In the case of Firm B, this was only after three years of machine tool manufacturing; the other *chaebol* firms had marginally greater experience of conventional production, typically five years.

On entering the machine tool industry, all the firms had previous experience of operating machine tools, and, in the case of two small firms, experience in the production of other types of machinery. Two firms (B and H) obtained practical skills and experience of machine tool production through other companies. In the case of Firm B, the heavy machinery division bought an old independent machine tool company, which was in great financial difficulties at the time, and the original equipment from this plant and many of its personnel formed the basis of the new machine tool firm. In the case of Firm H, the founder of the firm had been a core designer at Firm G, and had acquired considerable experience and knowledge of the industry before setting up his own firm. Many of the other new employees also came from Firm G, and therefore were experienced in the skills required by this industry.

Table 6.1 Basic Characteristics of the Sample Firms

Firm	Original Business Area	Date Established	(a) Date Commenced Machine Tool Production	Date Commenced CNC Production	Range of Products	Importance of Chaebol Market
A	Automobiles	1967	1978	1983	Special Purpose Machines, Transfer Machines, and Machining Centres	High
B	Trading Company	1977	1977	1980	Lathes, Milling Machines, Machining Centres	Low
C	Armaments	1959	1976	1980	Lathes, Milling Machines, Machining Centres, and Gear Cutting Machines	Low
D	Bicycles	1976	1977	1982	Presses, Lathes, Milling Machines, and Machining Centres	High
E	Heavy Industrial Forging and Machining Shop	1937	1976	1981	Boring Machines, Milling Machines, and Lathes	Low
F	Coal Briquette Machinery	1952	1960	1977	Lathes, Milling Machines, Grinding Machines, and Machining Centres	
G	Foundry	late 1940s	1950	1983	Lathes and Milling Machines	
H	Machine Tools	1968	1968	1983	Milling Machines	
I	Printing Machinery	1945	1965	1978	Lathes and Milling Machines	

a. For chaebol, date when group was established or date when division to manufacture machine tools was established.

Source: Firm Data

There are two broad types of product strategies represented among the sample firms: those specialising in the manufacture of special purpose and highly end-use orientated types of machines, and those principally manufacturing standard types of general purpose machine tools. All the independent firms are in the latter group, although Firm F does manufacture some specialised machine tools and lines of machine tools, principally for the car industry but also for mould producers. Two firms in the first category are the main vehicle producers (A and D), which manufacture special purpose machinery, mainly for use within their own vehicle plants or by their subcontractors. For these two firms, the internal *chaebol* market is large, while for the other non-specialising *chaebol* firms, the internal market for their products is less important.

Although *Chaebol B* is a major car producer, its car and machine tool production units are in different divisions within the *chaebol* and there are few links between the two. The reasons for this separation are not clear. However, this car producer is different from the other two vehicle producers as it is a joint venture with General Motors. Kim Young Woo has compared car production in *Chaebols A* and *B*, and noted that *B*'s joint-venture vehicle production imported the design of the cars it manufactured, and its localisation ratio was low, while *A* had initially licensed production, subsequently developed its own models, and raised its localisation rates (1981: 26-28). It may be that the car division in *Chaebol B* had in the past similarly procured the majority of its production machinery through its foreign parent company, or that its production equipment was specified by the parent with the design of the vehicles they manufacture.

Government Promotion

All the sample *chaebol* firms began machine tool production between 1976 and 1978. Almost all of these firms entered the industry in response to strong government promotion, and the influence of government was often referred to by interviewees. In all but one case (A), the new *chaebol* firms established their production facilities in the government-promoted and financed machinery complex at Changwon, and, as

such, benefitted from a range of government incentives. In the case of Firm B, the importance of government policy on the *chaebol's* decision to enter the industry is clearly indicated in a recent company brochure, which states that "Following government directives to develop the heavy industries in the early and mid 70s, [we] poured massive investments into the machine tool industry". In a similar vein, the chairman and founder of the whole *chaebol* clearly acknowledged the force of government policy in the 1970s and early 1980s, observing that when "the government tells you that it's your duty and you have to do it, even if there's no profit" (Charters, 1984).² Responding to the government's encouragement of the heavy machinery industries, this firm invested over US\$400 million in new production facilities in its heavy machinery division alone (further large investments were made by the group in other promoted sectors, such as shipbuilding). This type of investment by the *chaebol* was considerably subsidised by the government's provision of low-interest loans through the NIF. In interviews with Firms C and E, personnel also stated that a major factor influencing their entry at this time was government promotion of the industry, and, although no figures are available, these firms were also given considerable government backing through special loans and incentive measures. For example, Firm C was designated by the government as a "Manufacturer of Machine Tools" in 1978, and this then ensured the firm's access to government incentive measures.

For vehicle producing firms (A and D), the need to support their own production facilities was cited as a more important factor in their decision to enter the industry than promotion by the government. Firm D did, however, take advantage of government incentives to companies setting up in the Changwon Complex, while Firm A established its production facilities on the same site as its main vehicle plant. Thus, these firms' entry in support of vehicle production distinguishes them from the rest of the sample: their production range is aimed directly at supplying their own production machines, and their internal market for machine tools is the most important consideration.

The direct influence of government policy on the smaller independent machine tool firms was also acknowledged by two of the sample companies

(F and H). These firms expanded considerably during the late 1970s, with financial support from the government. Firm F established a new production facility in the Changwon Complex, created a centre for technical research at its original plant, concentrated more on product design, introduced some new models, and invested heavily in new imported production equipment. Jacobsson (1986: 189) notes that this firm received government financing of between US\$5 million and US\$10 million to undertake this expansion. Firm F also received several accolades from various governmental bodies for its industrial merit: these included being chosen as a "Quality Control Company" by the Ministry of Trade and Industry in 1975, a *Saemaul* Service Award for Exports in 1977, and appointment as a "First Grade Quality Control Factory" by the Industrial Advancement Administration in 1983. Firm H expanded rapidly after its move to a new larger site on the local industrial estate, and several Japanese machines were imported in 1977, with the use of government subsidised loans, to improve production facilities. This firm was selected by the Ministry of Trade and Industry as a "Specialised Machine Company in Metal Cutting Machine Tools" and was designated as a "Manufacturer of Export Products" in the late 1970s. The managing director stressed that his firm had been helped by government policies to promote the machinery industry and had also benefitted from their more recent policy to promote small and medium firms. The awards of the numerous accolades to both firms had tangible consequences: it meant that they had easier access to the various government schemes, and were consequently able to receive more government financial and technical support.

In contrast, the interviewee at Firm G stated that his firm was aware of the government's promotion of the industry, but it had received very little help. Although the firm had tried to obtain financial support through various government schemes, it had experienced great difficulties in the application process. The interviewee implied that the actual accessibility to the government's funding was very difficult. The remaining independent firm (I) suggested that the major help it had received from the government had not been from incentive schemes, but from various programmes run to help develop technical skills within the

firm. Only one of the *chaebol* firms (D) commented on the greater government promotion of the small and medium firms in the 1980s. This firm suggested that it had been discouraged from entering product areas which were more suited to production by smaller firms, such as small presses and small, basic machine tools. But in the production of larger machines, the firm was free to develop whatever products it wanted.

Thus, one undeniable outcome of government promotion was the entry of the *chaebol* firms into the machine tool industry, a consequence of the fact that *chaebol* firms were the major target of government encouragements. In some cases *chaebol* entry was an indirect effect of government promotion, which directly stimulated vehicle production. Independent firms were less important in the government's promotion strategy in the late 1970s, but, notably, more technically advanced and larger independent firms were significant beneficiaries of government encouragement.

Summary

Several different types of firms have been identified, each with different machine tool production strategies. The firms can be initially divided into two groups: those which are members of various *chaebol* (A-E) and those which are independent (F-I). Moreover, there are two types of *chaebol* firms: those firms which entered the machine tool industry with the specific aim of manufacturing and maintaining their own production equipment, and those which entered to supply the general machine tool market. These two types of *chaebol* firms have very different production strategies, the first group concentrating on special purpose machinery and the second specialising in general purpose machine tools. Of the independent firms, Firm F is different from the rest as it is far larger than the other three firms and has a very large production range. Government incentives to the industry were significant for the *chaebol* firms as well as for two of the independent firms.

The most notable feature of the sample firms' history is the means by which all of them - *chaebol* or independent, large or small - acquired

their base of skills in this area. Without exception, all firms gained knowledge of the operation, repair and maintenance of machine tools as users before they entered production themselves. These skills were invaluable in the translation from machine tool using to making, providing a capability base upon which new skills might be built up.

6.3 Levels of Production of Conventional and CNC Machine Tools

Changes in the level of output during the 1980s for several of the sample firms have already been noted. In two cases (Firms E and G), no information on growth or contraction in production was available. However, in both of these cases there was probably very little growth, if any, as they both were experiencing financial difficulties. All of the other firms grew during the period between 1981 and 1984. Table 6.2 shows the value of machine tools and parts, as well as general purpose metal working machine tools, produced by each of the sample firms in 1984. The metal working machine tool figures are broken down into CNC and conventional categories. The firms vary to a great extent in the scale of their production and in the proportion of their output devoted to the manufacture of the three major types of general purpose machine tools considered in this study (lathes, milling machines, and machining centres). Firms B, C and F are the three largest producers in the sample and in Korea. Combined, the value of their production amounted to over 50 billion won, representing over 70% of the total sample value and over 30% of overall Korean production in 1984. For all three of these firms, production is principally concentrated in the manufacture of general purpose machine tools; in each case over 80% of the value of total production came from the manufacture of the three types of standard metal cutting machine tools considered here. These three firms were also dominant in the production of CNC machine tools, manufacturing over 80% of total output.

The other six firms are all fairly small producers in comparison to the "big three", with annual value of production ranging from 1.6 billion to 5.1 billion won. Of these six firms, three (G, H and I) are independent firms whose principal product area is in the manufacture of general purpose metal cutting machines. The other three firms (A, D and E) are all part of different *chaebols*. These firms differ from the rest of the sample as they do not specialise in the production of general purpose metal cutting machine tools. In Firm E, a large proportion of total machine tool and parts production (over 50%) is in the manufacture of boring machines, grinding machines, and rollers. It has been noted in the

cases of Firms A and D that their production strategies were directly geared towards manufacturing equipment. In both these firms, special purpose machines account for a high proportion of output.

Table 6.2 Production of Machine Tools by Sample Firms in 1984
(in billion won; units in parenthesis)

Firm	Total Production ^a	Metal Cutting Production ^b	Conventional	CNC
A	4.4	(not known)	(not known)	0.3 ^c (2)
B	15.7	12.7 (715)	4.0 (491)	8.7 (224)
C	15.1	14.4 (2,225)	9.9 (2,141)	4.5 (94)
D	4.4	2.7 (146)	1.9 (133)	0.8 (13)
E	5.1	2.6 (356)	2.3 (332)	0.3 (24)
F	20.6	18.2 (2,169)	14.8 (2,106)	3.4 (63)
G	2.5	2.4 (291)	2.0 (277)	0.4 (14)
H	1.6	1.6 (224)	1.5 (222)	0.1 (2)
I	3.7	3.7 (695)	(not known) (680)	(15)
Total	73.1			
Total Korean Output	150			

- a. Includes production of all types of machine tools and machine parts/components.
b. Metal cutting production includes only the production of lathes, milling machines, and machining centres (drilling, boring, hobbing, and gear cutting machines were excluded).
c. Machining centres only; see text below.

Source: Firm data and Machine Tool, 1985, No. 9; 114-24.

Although the exact figures for the production of general metal cutting machines by Firm A are not available, circumstantial evidence suggests that this comprises only a small proportion of its general machine tool output. In 1984, this firm manufactured special purpose machinery to a value of 1.6 billion won, "other metal cutting machines" (i.e., of non-standard type) worth 1 billion won, and hobbing, drilling and gear shaping machines worth 1.4 billion won (Machine Tool, 1985, No. 9: 118-23). Thus, of this firm's total machinery output, 60% was in special purpose or unusual types of machine and a further 30% was in the manufacture of more general metal cutting machines not covered in detail in this study. Therefore, the two machining centres manufactured in 1984 probably represent the firm's sole production of the specific types of machines under consideration.

Production data for the general purpose machines made by each firm are broken down in Table 6.2 to show the quantity of conventional and CNC machines of this type. In eight of the firms, the production of conventional machines accounted for the majority of their sales. For these firms, the proportion of output by value represented by CNC machines ranged from 6% to 31%, with an average of 20%. Only in Firm B was the majority of production, 69% by value, in CNC machine tools. As the unit value of CNC machines is much higher than the average unit value of conventional machines, it is not surprising that, when expressed in terms of units, the proportion of CNC machines to total production is extremely low. In eight of the nine firms the proportion was less than 10%, with an average of only 5%.

Growing proportions of CNC production indicate that a firm has absorbed the intricacies of the new technology and organised its production for this new product area. Further, the transition from dependence on conventional production to CNC manufacturing, and the scale of CNC production, reveals a firm's ability to compete with its new product in the marketplace. While only one of the sample firms in 1985 had achieved a transition to CNC concentration, it would, however, be a mistake to imply that only this one has successfully entered CNC production. Two of the firms (C and F) produce a significant number of

CNC machines each year (84 and 63 respectively), and four others (D, E, G and I) have obviously progressed further than the manufacture of single "one-off" prototype or experimental CNC machines, with production levels of 13, 24, 14 and 15 units per annum, respectively. For the remaining two firms (A and H), CNC production was very low indeed and provided these firms with few sales.

Finally, scale in itself is an important measure, since increases in the scale of production can, as the career of the Japanese machine tool industry has adequately demonstrated, improve cost competitiveness. Jacobsson suggests that production of over 100 CNC lathes a year gives manufacturers a large proportion of cost advantages available to them through economies of scale, while output of between 500-700 will give them all the available cost reductions (1986: 100). In the production of milling machines and machining centres, scale economies may be achieved at slightly lower levels of production, due to higher levels of value added in their manufacture. Only in the leading three firms is it likely that any economies of scale in production are being achieved either from production methods used within the factory or the bulk purchase of components. But as CNC production in each of these firms is spread over different types of CNC machines, any cost savings through scale economies are probably very small.

Major Markets for Sample Firms

What is the market for machine tools produced by these firms? Specifically, what is the relative importance of domestic and foreign markets? Table 6.3 shows the value of machine tools exported by sample firms in 1983 and 1984 and the approximate proportions of total machine tool production and CNC machine tool production exported.

Of the sample firms, only one (A) had no exports or experience of exports up to 1985; all the other firms exported at some level. The combined exports of the rest of the sample form a highly significant proportion of total Korean machine tool exports, accounting for 71% and 64% of total Korean exports in 1983 and 1984 respectively. Approximately

90% of the sample's exports are accounted for by just four firms (B, C, F and I), of which C is the dominant exporter, this firm alone accounting for over a quarter of Korea's total exports.

Table 6.3 Exports of Machine Tools by Sample Firms

<u>Firm</u>	<u>Exports</u>		<u>%age of production exported</u>	<u>%age of CNC production exported</u>
	1983 (in thousand US\$)	1984		
A	0	0		
B	3,879	4,535	35	35
C	7,249	7,375	60	70
D	226	118	5	2
E	400	713	30	0
F	2,276	2,498	7	- ^a
G	113	198	7	10
H	335	491	40	0
I	1,182	1,773	40	10
Sample Total	15,660	17,701		
Total Korean Exports	22,020	27,524		

a. This firm does export CNC machines, but proportion is unknown.

Source: Machine Tool, 1984, No 8: 98, and as Table 6.2.

These data also give an indication of the export orientation of each firm. Thus, Firm C is more export orientated than the other firms, exporting 60% of its total machine tool production. Several other firms (B, E, H, and I) exported a significant proportion of their total production, between 30% and 40%. Of the remaining firms (D, F and G),

exports form only a minor part, less than 10%, of total sales. In the case of Firm F, however, because its overall production level is very high, this small percentage amounts to a large absolute export value. Firm F concentrates principally on the domestic market and estimates that it had a 35% share (by value) of the domestic market.

Only two firms (B and C) have successfully entered the world market for CNC machine tools. They lead in absolute value of exports, as well as in the proportion of their machine tool output sold abroad - 70% of Firm C's and 35% of Firm B's (by value) being sold abroad. For all the other firms, CNC machine tools are either not exported or account for only a very small proportion of their CNC production. The numbers of CNC machines exported by these firms were in single figures. Although the proportion of CNC machines exported by Firm F was not available, the interview established that a few CNC machine tools had in fact been exported.

As a whole, exports of the sample firms were directed towards markets in industrialised countries, rather than those of developing countries and other NICs. For most of the exporting firms, the major overseas markets are in the US, Japan, Canada, and, to a lesser extent, Europe. Taken together, the markets of these industrialised countries accounted for about 80% of machines exported by the sample firms. The major markets for the remaining 20% of exports are in Southeast and East Asia, Malaysia and Indonesia being the principal customers. For only one firm in the sample was this pattern reversed. 90% of Firm H's exports went to Southeast and East Asia, while only 10% went to developed countries.

The three largest exporting firms have established a number of overseas offices to sell and distribute their products. *Chaebol* C has a large number of overseas offices, of which three, in the US, Japan, and West Germany, are closely linked to Firm C and were especially established for the sale of its machinery products. Firm B has established two overseas offices, one in the US and one in West Germany. These were set up primarily to service sales of CNC lathes, machining centres, and

robots. Firm F has similarly established its own marketing network in the US. The other exporting firms, and Firms B, C and F in countries where they have no offices, appoint specialist machine tool distributors or agents.

The Korean Domestic Market

Interviews and questionnaires were concerned to establish the importance of the domestic market to each of the producers, and, in particular, to determine what their clients' major products were. For all the *chaebol* firms and for Firm F, the major domestic buyers were the automobile industry and manufacturers of components for this industry. And all the firms anticipated that these two industries would remain as their major market in the foreseeable future. In the case of Firm F, sales to one particular domestic vehicle producer had amounted to approximately 5 billion won over the previous two years, about 15% of total production, including the installation of a new automatic line consisting of 25 CNC lathes. In 1985, Firm F had submitted a tender to the vehicle plant for a new 50-unit line. Several firms noted that die and mould producers supplying the plastics industry were important buyers of milling machines and machining centres.

For the two vehicle producers (A and D), internal demand is obviously very important, as their major motive for entering production was to support their own production facilities, and, as noted above, many of their products are specific to vehicle and vehicle component production. A large number of Firm A's machines are sold to subcontractors producing components for vehicle production and are closely linked to the *chaebol*. A director of the division estimated that the machine tool division had supplied machines to about 300 different subcontractors in this way.

Firm B differs from Firms A and D, because, although vehicle production is undertaken within the *chaebol*, only a small proportion of its production (about 10%) is utilised within the *chaebol* and only part of this is used within the vehicle producing division. In the main, the

products of this firm are of a more general purpose type and are not specific to the vehicle industry. One director of the division incorporating Firm B predicted that, with the introduction of FMS in many production areas of the group, internal demand for the products of the machine tool firm and its services would increase. Like Firm B, the internal *chaebol* markets for Firms C and E were not considered to be large. As the production work undertaken by Firm E in other parts of the group is of a very heavy nature, the machine tools it produces cannot be used internally, and, consequently, internal demand is negligible. Many of Firm C's own machines are used within its own factory; it does produce special purpose machines in-house when it needs them, but, relative to overall production, this internal demand is low, probably less than 5%.

6.4 The Development of Indigenous Technological Capabilities

How, and with what success, have CNC machine tool capabilities been acquired by the sample firms? Chapter 2 analysed the range of learning methods that can be used in building up indigenous technological capabilities in general, e.g., learning by adapting, learning by copying, learning by searching, learning by hiring, learning by supplying, and, finally, what has been called interactive learning. Which of these methods were used by sample firms, and with what consequences? The case study permits an assessment to be made of the relative importance of different learning techniques at different stages of development. This analysis also allows an examination of the different areas of capabilities which have been most difficult for the firms to acquire, and which were, therefore, the highest technical barriers to entry.

Four main sectors of technological capabilities and skills are considered: design, interfacing, production and assembly, and R&D. Chapters 2, 3 and 4 emphasised the great importance of acquiring an indigenous design capability: (i) to supply the domestic market with the production machinery it requires and to be able to tailor this machinery to specific domestic needs, and (ii) to remain competitive on the international market. Thus, the major part of this section is devoted to examining the acquisition of design skills. In analysing the acquisition of this capability, entry by each firm into the production of CNC machine tools and its subsequent development in the design and manufacture of CNC machines are considered individually. The proportion of custom design work undertaken by each of the firms is also treated here. Following sections consider the firms' overall experiences in acquiring interfacing and production and assembly skills, and the establishment of R&D facilities by two of the large firms is specially analysed.

6.4.1 Design Capabilities

In order to build up a picture of the development of CNC machine tool design capabilities in each firm, the origins of designs used by the firms have to be considered. Where did the design of each firm's first

CNC machine tool come from? What was the nature of subsequent CNC machine tool design undertaken? What assistance did firms receive from outside bodies? How much custom design work is undertaken? This type of work is undertaken by the firms either to adapt or produce machines which are specific to a certain process or production requirement. The indigenisation of these skills is, therefore, important to all domestic machine tool users as it can greatly influence the costs of specialised machinery and improve the productivity of machinery available on the domestic market.

Chapter 3 discussed two basic types of CNC machine tool design: retro-fitted machines, which are conventional machine tools that have been adapted to take CNC controls, and new machines which have been specially designed for CNC control. That chapter also considered alterations to configurations of machine tools following an increase in the range of functions that could be controlled by the control unit. These alterations resulted in new types of machine: the four-axis lathe, the slant bed lathe, and the machining centre. These machines are more complex in design than CNC lathes or milling machines. CNC machine design can therefore be divided into three categories: retro-fitted machines, basic CNC machines, and complex CNC machines. The depth of technological and design capabilities required to produce and design these different types increases through the three levels of design complexity. In the subsequent analysis of the designs produced by each firm, the type of design is clearly indicated in order to assess the complexity of design work being undertaken by the firm. Jacobsson's typology of CNC lathe design broadly categorises design types by age, i.e., "very old", "old", and "modern" (1986: 105-07). That typology needs to be refined on a more technical basis. While it is true that retro-fits were the first type of NC machines to be produced, followed by basic and complex machines, the progression may also be seen as a feature of the learning process. By breaking down the different machines into their relative complexities, it is possible to show the extent to which an understanding of the operating principles of each type of machine has been absorbed.

Firm A

This firm used a licensing agreement for the development of its first CNC machine tool, a machining centre, and has also used licensing agreements to manufacture a new hobbing machine and a new special purpose machine. All these agreements were with Japanese companies. In each of the licensing agreements, the firm insisted that some training at the licensee's plant be included. Consequently, many of the firm's design engineers have had between three and six months training in a Japanese plant. The interviewee observed that the major benefit of using licensing agreements derived from that training, as it enabled the firm to acquire highly skilled personnel within a short time.

Although this firm has not designed its own CNC machine tools, its design department has developed special purpose machine tools for use in its own car plant and by its subcontractors. Indeed, this is a major element of the design work undertaken by the firm, and almost a quarter of the personnel in the design department work full-time in this area. A second important area of work of the machine design department is the improvement of productivity and quality control. As productivity improvements in the manufacture of vehicles is an important goal in this firm, the interviewee stressed that a main design requirement is to keep machinery as simple as possible. The firm had found that greater sophistication in its machinery often decreased operating speed, while simplicity enhanced versatility of use. Thus, while this firm does not have much experience in the design of complex CNC machine tools, design capabilities within the firm are high, and are principally directed towards the development of machinery for specific requirements and for improving the productivity of car production.

Firm B

Although this firm entered the machine tool industry by taking over an established producer, its first machine tool (a conventional lathe) was produced under a licensing agreement with a Japanese company. Its first CNC machine, a basic engine lathe retro-fitted with controls, was built in

1979 and was developed within the firm. This machine was very basic but unreliable in operation, and, consequently, was not commercially viable. Following this initial attempt, the firm designed and produced various new CNC lathes: all these machines were of a basic design, but were not simple retro-fits. Jacobsson (1986: 185) documents this firm's production of a total of six different designs of basic CNC lathes between 1980 and 1982, of which only the last was manufactured and sold in significant numbers (approximately 140 units). Although no formal technology agreements were entered into by the firm to acquire this design, the design team principally copied a Japanese CNC lathe, but fitted their machine with a lower powered motor.

At the end of 1982, the design department commenced a new project to develop a series of CNC lathes. The project was completed in 1984, and there are four lathes of complex design, including one with a slant bed. A small, simple robotic arm, which could be attached to the CNC lathes to undertake material handling operations, had also been developed and produced in small numbers. The firm continued to produce a fifth model of CNC lathe, using one of its earlier designs. Although this machine is of a basic design, it is much larger and of heavier duty, thus complementing the other lathes in the series. This range of lathes has been fairly successful, accounting for the majority of CNC machines produced in 1984 and 1985, and machines from this range are also the firm's principal CNC exports.

Entry into the production of machining centres followed the firm's CNC lathe developments. The first machining centre (horizontal) was produced under licence from a Japanese company in 1980. A second foreign technology agreement for a horizontal machining centre was entered into in May 1983, again with a Japanese company. Instead of using a licensing agreement, a co-production agreement was used here, since the firm felt that there would be fewer restrictions on alterations to the machine and on its export. Having used the co-production agreement for two years, the firm wanted to renegotiate to make it a standard licensing agreement. The reasoning behind this seemingly backward step was the firm's belief that it had been given none of the details of the machine design or its

control unit, and, by entering a licensing agreement, it would learn more about the principles behind the design. Also in 1983, a new licensing agreement for a vertical machining centre was negotiated, this time with a West German company. Firm B has also entered into other licensing agreements with Japanese firms to produce a tool grinder and a boring machine. While the firm is expanding its product range, it does not produce any special purpose machinery and the proportion of custom design work it undertakes is minimal.

Firm B has thus followed two different strategies in the design of its CNC machine tools, having used indigenous designs for its CNC lathes and foreign technology agreements to produce machining centres. And while the firm has indigenised the design capabilities required to develop new and complex CNC lathes, it does not yet have the capabilities independently to design machining centres. Jacobsson (1986: 186) suggests that these two different strategies were followed because the firm felt unable to stay at the international frontier for both products, and therefore concentrated its own design efforts on the development of CNC lathes. While this suggestion is plausible, it does not adequately take into account the greater complexities of designing machining centres compared to CNC lathes.

Firm C

This firm has many foreign links, and it therefore has had a substantial input of foreign technology, particularly in the form of foreign experts working in the Korean plant.³ The majority of these foreign workers are located in the firm's design and development office. It entered into a joint project with a Japanese firm to produce its first machining centre in 1981. In 1982 the firm acquired a West German machine tool company and used the German designs for two horizontal machining centres it started to produce in 1983. The design group in Korea, a combination of Korean and foreign engineers, has also designed three machining centres, two of which are of the same design but of different sizes. All five machining centres have high-powered spindle motors, between 15 and 22 kW, and there must be ample rigidity in the

design and construction of the machine to take these large motors. A retro-fitted milling machine, with a small (3.7 kW) spindle motor, was an early development by the firm's design group and is still manufactured.

In 1985, Firm C produced only one type of CNC lathe, using its own design, again with fairly large motor power (18.5 KW). At the same time, the firm acquired a 75% holding in another West German producer. It is highly probable that designs, and design skills, will be transferred from the German to the Korean company, in order to upgrade its lathe production, just as machining centre technology was transferred from its other German subsidiary. Firm C was then also manufacturing prototypes of its internally designed gear shaping, gear hobbing, and gear shaving machines, all with CNC controls. Again, these machines were being designed in-house, with considerable design input from the firm's foreign employees. These were the first of these types of CNC machines to be designed and produced in Korea. The design group also undertakes a considerable amount of custom design work, principally developing special purpose machines, which are becoming an important feature of the firm's output. The interviewee estimated that approximately 30% to 40% of design work was in the development of special purpose machinery.

This firm has considerable capabilities in the design and development of standard and complex CNC machine tools. In the main, these capabilities have been built up through buying in foreign technology by two means: firstly, by employing highly skilled and experienced foreign engineers; secondly, by acquiring foreign enterprises and transferring skills from the foreign firm. These foreign technology inputs are acknowledged by the firm's executive president:

As a result of the early introduction of modern technology from the United States, the United Kingdom, West Germany and Japan, ... [we have] the experience, the facilities and the personnel to do the job better and on time (Firm Brochure, n.d.).

Firm D

This firm has very close connections with a Japanese company from which they have licensed several different machine tool designs. In the firm's initial manufacture of conventional machine tools, it produced milling machines, grinding machines, and a turret lathe under licence from this Japanese firm. These licences incorporated all production details required for the manufacture of the machines. In addition, under the agreement, the Japanese firm sent an engineer to work in the Korean factory in order to train Korean personnel in all areas of production - "from the bottom to the top" (interview with Japanese licensor). Although the licence for the milling machine is no longer in operation, the firm still sells them under an amalgamated name of the Korean and Japanese companies. The design of this machine was developed using the originally licensed design as a guide, but the firm wanted to retain the Japanese image, considering that under the joint name the machine had more "credibility" on the domestic market.

Before entering CNC machine production, Firm D bought several foreign CNC machines for in-house study. It also sought information on the operation and production of CNC machines from KIST and on the control unit from Fanuc. The firm's first CNC machine, a milling machine, was produced at the end of 1981 using an indigenously developed design. Although this machine was not a retro-fit or an exact copy of a foreign machine, the basic design of its milling machine was altered to take CNC controls, and the foreign machines on the shop floor were an important source of additional operational and technical information. A second CNC milling machine was similarly developed in 1982. In 1983, the firm entered into a collaborative project with KIST, and a machining centre was jointly developed. Less than ten units of this model were produced and they were all sold to another *chaebol*.

It was only after these machines had been developed and produced that the firm entered into licensing agreements to acquire the designs of a machining centre and a CNC lathe. (In the firm's sales literature this lathe is referred to as a turning centre, but it is a fairly standard

two-axis CNC lathe, with no additional controlled features.) Both these agreements were with the same Japanese firm from which the licences for the conventional machines were obtained. Like the licences for conventional machines, these agreements included the total specifications of the machines, all the design information, as well as information on the production process. The inclusion of production technology was an important input for the firm, as it has greatly helped its build up of internal capabilities and improved the quality of its products. Subsequent to this licensing agreement, the firm upgraded the horizontal machining centre it developed with KIST, and now produces about 40 units a year of this model. The firm has also continued to maintain close, but informal, links with its Japanese licensor.

A high proportion of this firm's production is in special purpose machine tools, and about half of its design work is devoted to custom design. Indeed, this is an area in which the firm has considerable skills. Since the firm first started to work with CNC machine tools in 1981, it has built on its base of design skills and is capable of developing its own basic CNC designs. The firm has received considerable help in its acquisition of the skills required to design more complex CNC machine tools. While it has utilised the knowledge it acquired through a licensing agreement to improve an existing machining centre design, the firm would probably have many difficulties if it wanted to develop an entirely new model of machining centre, as it would almost certainly have in designing a complex CNC lathe. The firm lacks design experience at the relevant level, and because the main design emphasis is on special purpose and customised machines, the number of designers able to work on such a project are small.

Firm E

Firm E started to produce machine tools in 1976 using several licensing agreements with Japanese companies in the production of milling machines, boring machines, and lathes. The licences included drawings, process plans, working diagrams, and the supply of some basic raw materials. These agreements contributed to the early accumulation of

technical knowledge and design capability within the firm. The first CNC machine, a milling machine, was produced in 1981 using skills built up within the firm since 1976. A machining centre was developed in collaboration with KIST in 1982-83 as part of a national project, and was mainly government funded. However, since the firm could not find a market for it, this machine was never produced commercially. The firm has also designed and produced a very basic CNC engine lathe, with technical help from the Japanese licensor of the original conventional lathe. This machine is simple, low-powered, and cheap, selling for about half the price of most CNC lathes on the Korean market.

The firm has also designed the body of a CNC milling machine in collaboration with a Japanese company. The machine bodies are manufactured by the firm in Korea and exported to the Japanese company, which then fits the controls and sells them under its own name. Although it is now fairly common practice in the machine tool industry for the more labour-intensive, mechanical body to be subcontracted by firms in high-wage countries to producers in lower-wage countries, it is interesting that in this case some of the design work was also contracted out to the Korean firm. While this firm has adequate skills to undertake the design of both a basic CNC milling machine and a simple retro-fitted lathe, it does not yet have the skills required to design more complex CNC machines, nor does it have much experience in custom design, as only a very small amount (less than 10%) of its design output is in this field.

Firm F

The first CNC lathe built by Firm F in early 1976 was also the first CNC machine tool developed in Korea and the first collaborative project to design a CNC machine that KIST entered into. The machine tool body (a conventional lathe) was built by Firm F and then retro-fitted with a stepper motor and a control unit by researchers at KIST, who also undertook some basic design alterations. A working proto-type of the new machine was fabricated by December 1976. This lathe was purely for development and experimentation purposes and was never produced in quantity. In 1977, a second CNC lathe was developed with KIST; this

machine was fitted with higher powered servo-motors rather than steppa motors. Several units of this machine were produced and used by the firm in-house. (These early machines were still in use in one of the firm's plants in 1985.) Again, this machine was not commercially developed, since there were several technical problems with it. The machine was, however, displayed at the first Korean Machinery Exhibition in 1977 and at international machine tool fairs in the US and West Germany.

In 1977, Firm F entered into a licensing agreement for a CNC lathe with a Japanese company, and this agreement was utilised by the firm over a period of three years. Although the firm did not produce or sell many of this model, it did acquire detailed technical information and production know-how from the licensee. As well as using a licensing agreement to acquire foreign technology, the firm sent several technicians to Japan and the United States for training. The interviewee said that the main motivation for sending these engineers abroad and for using the licensing agreement was not just to acquire technology but to improve the quality of its products.

The firm has subsequently designed and developed several CNC lathes, a special four-axis lathe for use by a car producer, and in 1985, it started to design its own turning centre. Using the experience the firm had gained in the design and production of CNC lathes, it began to produce CNC milling machines and machining centres. A CNC milling machine was first developed in 1981-82, followed by a CNC copy mill in 1985. (This particular machine was specially designed to meet growing demand for specialised milling machines from Korean mould producers.) In 1983, the firm designed and started to produce its own machining centre, only a few of which have been sold.

Firm F has a very competent and experienced design department and is widely regarded in Korea as the leading domestic problem-solving firm. It not only possesses the capabilities to design complex CNC machines but also has considerable experience in the design and production of lines of machinery for use in the car industry. Although the firm's products are

principally standard general purpose machine tools, it does undertake a fairly high proportion of custom design work.

Firm G

Between 1975 and 1981, Firm G had very close links with a Japanese company through which it obtained designs for three different models of milling machine. The technology agreement through which the designs were transferred was very comprehensive. The Korean firm acquired the whole set of blueprints for the machines, including all the detailed design and assembly drawings, as well as the basic machine drawings and specifications. Furthermore, the Japanese company trained some of the Korean firm's technicians, and a Japanese technician worked in the Korean plant for a time to help with production. Finally, some key components, for example, the gears, bearings and some of the electrical parts not produced locally were also supplied by the Japanese firm. The exact form of this agreement is unclear; the interviewee referred to it as "a technology co-operation agreement", but, since there was no technical input by the Korean firm, this seems an inadequate description. As the designs transferred were fairly basic and old, and as the Korean firm was allowed to make alterations to the design, the agreement was not as restrictive as most licensing agreements.

In 1983, the firm retro-fitted its turret mill by changing the motors and drives and interfacing it to a control unit. Although the formal agreement with the Japanese firm ended in 1981, Firm G did receive some help from its former collaborator, and the machine is sold under the names of both the Korean and Japanese firms. The interviewee commented that the Japanese name adds extra "legitimacy" to the machine and helps in the marketing of the machine in Korea where Japanese products are widely thought to be vastly superior. (This is similar to the case of Firm D which still sells its milling machines under its former licensor's name.) With only minor changes, this machine has continued to be Firm G's only CNC product.

In spite of comprehensive technical aid from the Japanese company, Firm G has the lowest design capabilities among sample companies. The design department is extremely weak and the firm has had great difficulties recruiting both experienced designers and graduate engineers. When the firm was visited in 1985, three of the four employees in the design department were young engineers who had been seconded as part of their military service to work in the factory. Without considerable internal training and the extension of the firm's technical links with the Japanese company, it is unlikely that the situation will improve. One of the firm's core designers left because he felt that the management was uninterested in developing new products, and this may be taken as one indication that radical changes in management attitude are required for the firm to acquire suitable skills.

Firm H

Firm H was established in 1968 by a design engineer who left Firm G. This designer wanted to develop a heavy duty milling machine, and, as Firm G did not wish to enter this product sector, he established his own company. This man is still the managing director; he is knowledgeable in the design of machine tools and keen to develop new and improved designs. The firm has continued to specialise in the production of heavy duty milling machines, and, has had considerable success in exporting to other Southeast Asian countries.

In 1981, it developed its first CNC milling machine. To gather information on CNC machine specifications, the firm collected and studied catalogues and technical materials for Japanese manufactured CNC mills. The firm also participated in a CNC school that had then been set up at KIST. The design for the new CNC machine was developed in Firm H, and was based on the large milling machine which is that firm's principal product. This design was then reviewed and improved in collaboration with researchers at KIST.

The managing director of Firm H considered that machining centres would come to dominate the CNC market in future and that the firm should

enter this product sector, but he also felt that, as the firm's design and production experience was in the manufacture of milling machines, it did not have the capabilities to undertake this work. The firm has, however, bought two machining centres from Japan for use in its factory in order to improve productivity and the quality of its milling machines, and to learn about the operation of machining centres. The managing director said that he would also like the firm to enter a licensing agreement for a machining centre, but had as yet been unable to find a licensor. He was, however, very reluctant, for political and historic reasons, to enter a licensing agreement with a Japanese firm, and this had made the search for a licensor difficult.

Because of this firm's origins, design has always been regarded as important. In the specialised field in which the firm operates, its capabilities are very good and it has built up the skills needed to design basic CNC milling machines. However, the firm recognises that without design support from outside, it will not be able to develop a machining centre.

Firm I

This firm developed a CNC lathe in a collaborative project with KIST in 1978-79. KIST actually developed two lathes during this project: the first was a simple retro-fit and the second a basic CNC lathe. Since this second model was brought into production (in very small quantities), the firm has not adapted or developed it any further. In 1985, the firm was very anxious to increase its production of CNC machine tools and to develop new models. Although the firm had the design skills to develop new conventional machines and, possibly, retro-fitted CNC machines, it did not have the ability to develop a new basic CNC machine.

In order to enhance its design skills and start manufacturing a new CNC lathe, the firm entered into a collaborative project with the SMIPC. This project commenced at the beginning of 1985, and the firm was hoping to start producing the machine by the end of that year. It was also considering entering a licensing agreement with an American company to

start producing a small CNC lathe. In 1982, this American firm established a joint venture with another Korean company, which undertakes casting and basic machining work for export to the US, as well as producing a few conventional lathes, to the American company's design, for the Korean market. Firm I has very close links with this American-Korean firm and with engineers from the American parent company, who were based in Korea to support the joint venture, the visiting American engineers often advising Firm I in various technical areas.

Analysis of Firms' Design Capabilities

There is a spectrum of design capabilities in the sample firms. The large general purpose producers (B, C and F) have the highest levels of such skills, and these three are also the largest CNC machine tool producers, manufacturing the broadest range of CNC machinery. All three firms have the capability to design new complex lathes, and Firms C and F have both developed machining centres, although Firm F's machine has not been particularly successful on the domestic market. The *chaebol* firms dedicated to the manufacture of equipment for their own vehicle production (A and D) both have substantial levels of design skills in the development of special purpose machinery and in the customisation of machinery. As these two firms have only acquired skills in the design of general purpose machinery as a supplement to their other design skills, their ability in this area is not as advanced as that of the large general purpose producers. However, the two types of design skills are, to some extent, transferrable and, therefore, the development of both these design capabilities has been complementary. Of the remaining firms, three (E, H and I) have the design capabilities to develop retro-fitted machines and very basic CNC machines, but require design support for the development of more complex CNC machine tools. Finally, Firm G has the weakest design department of the sample firms and would have difficulties if it wanted to develop any new machine tool independently. Most of the sample firms undertake some custom design work, but, with the exception of Firms A and D, this is not an area of design essential for their future product development. However, for one firm in particular (C), this was becoming a more important design area, as its production of special purpose machines was increasing.

The figures in Table 6.4 are only a very rough estimate of the number and specialisation of personnel in each firm undertaking design work, since firms' interpretations of core and basic design differed. Nevertheless, the figures do reflect each firm's relative design strengths. Firms A, B, C, D, and F have the largest design departments, each with over 30 employees. Firms E, H, and I have sizeable design departments, and a significant number of personnel are working in core design. Firm G

had no core designers at all, and only four detail designers. With the exception of Firm G, which employed no electrical engineers, the ratios of mechanical to electrical engineers in each firm were approximately the same (4:1). (The next section surveys in detail the mechanisms by which electronics skills have been acquired.) While this ratio indicates the growing importance of electrical engineers in an industry traditionally dominated by mechanical engineers, compared to machine tool firms in Japan this ratio is still high. (In Japanese firms, the ratio is more commonly 2:1, and in some cases has equality.)

Table 6.4 Design Personnel in Sample Firms

Firm	Number of Employees			Ratio of Mechanical/ Electrical
	Total in Firm	Core Design ^a	Detailed Design	
A	314	30	50	4:1
B	1800 ^b		80 ^c	3:1
C	3280 ^b	160 ^b	20 ^b	---
D	955	30	11	4:1
E	---		20 ^c	4:1
F	725	24	11	4:1
G	159	0	4	(All Mech.)
H	99	9	2	---
I	185	5	5	4:1

a. Personnel employed in this area undertake core design, custom design, and some new product development.

b. Includes personnel in other manufacturing areas as well as machine tool production.

c. Total design personnel

--- Figures unavailable

Source: Firm Data.

The build up of design skills from the development of basic and retro-fitted machines to the successful development of complex CNC machine tools has been an extended process. Firm B first developed a retro-fitted CNC lathe in 1979, but took five more years to successfully develop a complex CNC lathe. Firm F produced its first CNC lathe in 1976, but it was only in 1984 that it too started to produce complex CNC lathes. In several cases (E, H and I), even though the firms had many

years of experience of basic CNC production, in 1985 they still did not have the capabilities within the firm for complex CNC designs. For example, Firm I developed its first CNC machine tool, a basic lathe, in 1978-79, and by 1985 had not developed a new model on its own.

The bigger firms have achieved greater success in the absorption of design skills. These firms had the resources which enabled them to "buy in" the skills they were missing, and, hence, to build up larger and more able design departments. In the process of acquiring new design capabilities, these firms extensively utilised foreign sources of technology: licensing agreements, the employment of foreign technicians, and sending their employees abroad for training. These firms now possess a "critical mass" of skills within their design departments (they all have more than 20 core designers) and are able to sustain future product developments. For smaller producers, this sort of technical and design development was not possible and, consequently, it is taking them longer to build up their design departments.

In general, the bigger firms have been more successful in indigenising the design skills for complex CNC lathes than for machining centres. It might be thought that this situation stems from the firms' longer experience with CNC lathes than with machining centres. However, this is unlikely to be the whole explanation. The far greater complexity of machining centres compared to CNC lathes seems to be an important consideration. The prevalence of foreign technology agreements for machining centres indicates that this technology is harder to assimilate. Indeed, repeat licences in this technology are not uncommon.

While many of the design techniques gained through the production of lathes could be transferred to the production of other types of CNC machines, the design of a machining centre is inherently more difficult than the design of a complex CNC lathe. Compared to a CNC lathe, machining centres have more axes to be controlled simultaneously than a CNC lathe. This increases the complexity of the design as there is a larger number of moving parts. Ensuring that the machine is rigid, and therefore accurate, in operation is also far harder to achieve on a

machining centre than on a CNC lathe. On a lathe, the bed and the main spindle are rigid and static; movement on the axes is provided by moving only a turret which holds the fixed cutting tools along slides on the bed. However, the major parts of the machining centre - the bed and the head including the main spindle and its motor - have to be mobile to provide movement along the various axes. The movement of these fairly large and heavy parts has to be achieved without excessive vibration or backlash in the machine body, otherwise the machine's accuracy will be eroded and the quality of the cut will be poor due to "chatter".⁴ The design of a machining centre is further complicated by the requirement to fit an automatic tool changer to the machine. On a CNC lathe different tools are fixed in a turret when the machine is set up and these turrets usually carry a maximum of twelve tools. Machining centres have to have a larger supply of tools, and the cutting tool in the spindle must be removed and replaced automatically from the tool store. This means that tools cannot be pre-set in their cutting position when the machine is set up, and some type of mechanical device to remove and replace tools has to be developed.⁵

While the smaller and less dynamic firms still have many gaps in their design abilities, the leading Korean CNC machine tool producers have made significant progress towards acquiring a comprehensive design capability. The leading firms are no longer totally reliant on foreign technology, either through formal agreements or informal transfer (e.g., copying), in order to develop new models. Most of these firms have also acquired some skills in the design of special purpose and customised machinery. (These latter skills are mainly concentrated in those firms which are directly linked to vehicle producers.) The acquisition of both these types of skills means that machine tool producers are now able to undertake one of their most important functions within the economy: the support of product and productivity developments in other sectors of Korean manufacturing industry.

6.4.2 Interfacing Skills

Microelectronics skills have been regarded as a problematic area for conventional producers, mainly because they have no existing knowledge in this field. Generally, it was felt by the machine tool firms and staff at research institutes that there had been little difficulty in learning how to design and build interfaces, i.e., the circuitry required to connect control unit and machine tool. Producers either trained existing personnel within the firm or recruited new personnel. (It was noted in the previous section that approximately a quarter of design personnel in the sample firms are skilled in electronics design, and interfacing is one of their main tasks.) In addition, all the producers at some time went to outside agencies for help in acquiring or improving these skills. There were four different means by which the firms could acquire interfacing skills, although some of the firms used more than one learning method. These are described in order of their importance.

The most important source of information and aid was the controls producer, nearly always Fanuc, and much of this help came through a joint venture Fanuc established in Korea in 1978. (This joint venture is discussed in more detail later.) Secondly, researchers at KIST were an important source of advice during collaborative projects. Many KIST researchers were initially trained by Fanuc, during the course of KIST's first CNC project in 1976. Thirdly, whenever the initial CNC machine tools were manufactured under licensing agreements, the design for the interface, and instructions on its assembly and attachment to the machine body, were also incorporated in that agreement. Some of the Korean firms established close ties with foreign firms in the design and development of both conventional and CNC machines, and they continued to obtain advice on the interface from the foreign companies even when they were no longer using the original licensing agreements. Fourthly, an interface could be bought "off the shelf" from the controls producer; however, this was regarded as a very expensive and unsatisfactory option.

The most important point here is that firms received substantial help from Fanuc, directly and indirectly, in the training of personnel.

Any barrier to entry that may have been created by this new skill requirement was therefore greatly lowered by the support offered by this controls producer. In a related study, Fransman found that Fanuc had assisted Taiwanese CNC machine tool entrants in solving problems they encountered with interfaces. Fransman seems to find Fanuc's role in this connection rather puzzling, commenting that, "somewhat paradoxically, Fanuc, the major supplier of CNC controls to Japanese firms, was also helping to cultivate competition for these firms from Taiwanese producers" (Fransman, 1986a: 183). The paradox Fransman points to involves the contradiction between this assistance to Taiwanese producers and Fanuc's traditionally close links with Japanese CNC machine tool firms. However, the paradox may only be an apparent one. Fanuc's main aim must be to expand its own market share, not only of the domestic market but also of the world market.⁶ Furthermore, if Fanuc was not receptive to the approaches of the Korean (or Taiwanese) producers wishing to buy control units and acquire interfacing skills, the new entrants would have purchased controls from other, smaller Japanese producers or from American companies. Entry into these markets may subsequently have been very difficult for Fanuc, if another producer had established a high level of customer loyalty, just as Fanuc have now made it very difficult for other controls producers to enter the Korean market. For these reasons, Fanuc offered not only comprehensive customer support and training, but also provided similar training for research institutes in the anticipation that familiarity in training with their equipment would lead to further sales to existing producers and new entrants. Moreover, it needs to be stressed that Fanuc's technical support to both Taiwanese and Korean producers does not extend beyond the interface to the "black box". Fanuc has never offered assistance to any producer in the design and construction of the more technically sophisticated and expensive control unit, nor will it allow customers for its control units to "open up the black box" and to modify it in any way.⁷ It would indeed be "paradoxical", from the point of view of Fanuc's market interests, should it offer the kind of assistance in control unit technology that it has given in interfaces.

Only one firm in the sample (H) chose first to buy an interface. The firm bought a programmable control interface with a control unit from Fanuc for its first CNC machine, as there was no one in the firm with sufficient electronics capabilities who could be trained in the required skills, and the firm did not want to employ a new engineer for a single job. This small firm did later build up its own electronics design and production capabilities by employing the brother-in-law of the managing director. (The brother-in-law had previously established his own small electronics firm, but abandoned this project in order to work for Firm H.) On joining the firm, he developed an interface for the CNC milling machine that the firm produces, thus replacing the purchased interface, and in interview expressed confidence that he would be able to develop new interfaces if the firm commenced production of any new CNC machines.

All of the firms in the sample, except for the small Firm G, had acquired the skills necessary to design and produce new interfaces for newly developed machines. As CNC production has become an important part of some producers' output, and as the indigenous design of these machines is increasing, so electronics has become a more important component of the design work undertaken. With the exception of Firm G, approximately 20% of the personnel in the firms' design departments specialised in electronics and electrical engineering, while the remaining 80% specialised in mechanical engineering. In the case of Firm G, since its design department is so small and since the firm has experienced great difficulties in employing new design and development staff, this firm is unlikely to be able to develop its own interfaces in the near future.

With the establishment of the SMIPC, a new source of help for small firms became available. The SMIPC runs various schemes enabling small firms to acquire new skills, either through financing technicians to travel abroad to be trained at other controls or machine tool producers, or by giving grants to finance foreign technicians to visit the Korean firm and to teach the appropriate skills. The SMIPC has also taken over some of the advisory and training functions that had been previously undertaken by KIST. This will probably be an important source for new

CNC entrants, and small firms like G will also be able to benefit from this technical support.

6.4.3 Mechanical and Assembly Skills

A previous section described entry by sample firms into the production of general machine tools. It was concluded that, as all of the firms had experience in mechanical engineering manufacture and the operation of machine tools, so the mechanical skills required for conventional machine tool production already existed within the companies. Similarly, since all the firms had experience in the production of conventional machines before they entered CNC production, these mechanical skills could easily be transferred to the production of CNC machines. However, although the majority of the mechanical skills were available in the firms, several firms did have reliability and quality problems with the CNC machines they first produced. Arguably, these problems serve to demonstrate a gap between the mechanical skills adequate for conventional production and those required by the new machines.

There were three main sources through which firms acquired more knowledge about the operation and construction of CNC machines, and assistance in improving their production techniques to solve these problems. Firstly, through the purchase of new CNC machinery, workshop personnel gained practical experience with these machines which helped their understanding of the operating principles behind the new machines they were assembling and testing. The purchase of new machinery also improved the quality of the components and machined parts manufactured by the firms. Secondly, in several of the licensing agreements outlined above, production information was included in the technology package. For example, in the licensing agreements entered into by Firm D for a machining centre and a CNC lathe, information and technical advice on production processes were included, and this was regarded by the firm as a significant input in the improvement of its production capabilities. Similarly, the interviewee in Firm F noted the importance of detailed technical information and production know-how included in the licensing

agreement it entered into in 1977, even though it only produced a limited number of machines under this agreement. These firms were able to utilise such improvements in production techniques in all production areas.

Thirdly, technical personnel in several firms were trained by skilled foreign engineers. This training was undertaken in two ways: either Korean technical personnel were sent overseas for training in an established plant or skilled technical personnel from overseas firms worked in the Korean plant to oversee production, help train production personnel, and solve production and quality problems. Examples of this type of skill transfer come from several firms. Firm F sent several of its engineers to Japan and the US for such training, and in the case of Firm A this transfer of personnel to the licensor's plant for training was incorporated in its licensing agreements (these included training in other skill areas as well as production and quality control). In the case of Firm D, an engineer from its Japanese licensor worked in the Korean plant for a time and trained some of its production personnel. Technicians in Firm G were trained by a Japanese firm with which it had a close relationship, and a Japanese technician worked at the Korean plant to solve production problems. The other two small independent firms (H and I) also received help from visiting overseas experts, subsidised through a scheme run by the SMIPC. All the firms now seem to have few difficulties with assembly and most have been able to improve the quality of their product.

6.4.4 R&D Capabilities

R&D capabilities are an important indication of whether producers have acquired an understanding of the principles of machine tool and automation technologies. Moreover, these capabilities allow firms to be innovative, enabling them to develop their own novel products, rather than simply following, and copying, product developments made in other firms and other countries. It should, however, be stressed that the work undertaken by these departments is basically developmental in nature and

there is no fundamental or basic research incorporated. Indeed, this is the case for the majority of firms in the global machine tool industry. Chapter 4 noted that traditionally there is little support for such basic research in the industry. In fact, many important machine tool developments have been the result of research undertaken either by users (often the defence industry) or component suppliers (e.g., tool makers and controls producers). Of the nine sample firms, only two (B and C) have sizeable departments undertaking R&D specifically on machine tools and related products. (The work of these two leading firms' research departments and the projects undertaken are considered in greater detail below.) The other *chaebol* firms (A, D, and E) all have R&D capabilities within the groups, but they are specific to other major products of the group. Of the independent firms, only F and H stated that they had a particular section of the firm working on R&D, and in 1984 the annual budgets for these departments were fairly small, at 200 and 150 million won respectively. The work of these two departments was principally an extension of the design departments, and, accordingly, is not considered here.

Firm B

This is the firm best equipped for undertaking R&D. It has a large team of engineers and technicians, based at the machine tool plant in Changwon, to support the machine tool manufacturing process, and to modify and adapt existing products. R&D work on new types of machines and automated systems is undertaken at a separate technical centre at Inchon, on the same site as the company's large engine manufacturing plant. This centre was established in 1982 and employs a total of 460 engineers and technicians. Prior to its establishment, all development work relating to machine tools was undertaken at the machine tool plant, and its projects were directly supervised by that plant's management team. The new technical centre does development work for all sections of the company, including diesel engine design technology, machine design and component technology, and industrial electronics. There are three main research groups within the centre whose work is directly related to machine tool production— laser machining, robotics, and factory automation — and the work of these groups will need to be more closely examined.

Table 6.5 Composition of Technical Skills in Research Groups of Firm B

Research Group	Number of Electrical and Electronics Engineering Personnel	Number of Mechanical Engineering Personnel
Laser Machining	30 (Electro-optics) 12 (Electronics/Laser)	18
Factory Automation	10	12
Robotics	16	8

Source: Firm Interview.

Table 6.5 gives details of the number and disciplines of the 106 research staff working in these three groups. A major feature of these groups is the heavy emphasis on electrical and electronic engineering, with over 60% of the engineers working in this discipline, while the remainder concentrate on mechanical engineering. Many of these employees have master's degrees from KAIST or from other leading universities in Seoul and a few have Ph.D.s from KAIST. Despite the fact that a high proportion of the researchers were trained by KAIST, there are no research links with this government institute at present. A small number of employees were trained or educated in the US: a technical director of the company obtained a Ph.D. in machine tool technology at an American university and several of the employees in the laser machining group have been trained in laser and optics technology in universities and laser plants in the US.

The laser machining group has developed two different types of laser machines: a laser machining centre and a laser marking machine. The designs for both of these machines were internally generated. This included the design of the control unit, but excluded the laser technology which was licensed from a laser manufacturer in the US. The firm had by early 1985 already sold several of these laser machining centres, including one which was exported to the US. The laser marker has not

enjoyed the same success, since the machine lacked a satisfactory material feeding unit. The research centre approached three American companies in an attempt to obtain the technology required to make this unit through a licensing or co-production agreement. But, as the technology was very new, none of these companies agreed. The technical group was therefore having an initial attempt at designing its own. This marking machine was developed specifically for the domestic market, since over 50 such machines had already been imported into Korea for use by the electronics industry. However, unless the materials handling problem is solved, these domestic users will continue to import rather than buy inadequate machinery from a domestic producer.

The robotics group has produced an articulated six-axis robot; this project included the development of the robot's control unit, based on a Motorola cpu. (This robot is a totally different development from the simple robotic arm developed by the design engineers at the machine tool plant in Changwon, and which is fixed to some of the firm's CNC lathes.) The first proto-type of the robot was built within a year and a second year was spent testing, re-designing and modifying both the mechanical elements and the hard- and software in the control unit. The company uses eight of its own robots in its various plants and has supplied a small number of robots to two other companies (undertaking car and ship production) within the *chaebol*. The robot was exhibited at the "Robot 9" trade fair in Detroit in 1984, and was subsequently marketed in the US. In this market the robot was priced at US\$30,000, approximately US\$5,000 less than similar Japanese robots. This price difference was attributed to lower design, production, and overhead costs compared to those incurred by Japanese producers. The firm hoped to sell between 50 and 100 robots in the US in 1986. The group was also in the process of developing a new robotic materials handling system for the electronics industry and painting robots for the *chaebol's* shipbuilding company.

The factory automation group studies the automation of different manufacturing operations within the manufacturing divisions of the entire *chaebol*. This group stipulates the engineering requirements for automation and decides which components of the system may be produced

in-house. Projects have included engine manufacture, fork-lift production, and television assembly. The group includes FMS in its work and has designed systems for use in its own air-frame production plant and in the vehicle plant of which Firm A is a part. The group was also in the very early stages of a design project for an FMS to be installed in its sister company's car plant. As this vehicle company is a joint venture with General Motors, the American company will provide the specifications for the new system, but its design and installation will be the responsibility of the Korean company.

Two important features of the work of these research groups should be noted. Firstly, the research groups covered have acquired high levels of microelectronics and controls knowledge, and the projects they have undertaken indicate their capabilities in these areas. These capabilities have been acquired by the company mainly through the recruitment of graduates from Korean universities and institutes, and only a very few of the company's research staff have been trained abroad. Secondly, while the machine tool plant and its design team had little contact with other divisions of the *chaebol*, the research teams covered here have all developed new products for use within various divisions of the *chaebol* as well as for other producers on the domestic and export markets. Thus, other manufacturing divisions of the *chaebol* are benefitting from the capability to manufacture complex production equipment that has been built up in this research group. In particular, it is important to note that technological links between the research group and the vehicle division of the *chaebol* have been established. It is highly probable that such collaboration may lead to much closer links between the vehicle producing and the machine tool manufacturing companies within this *chaebol*.

Firm C

This firm has a large design and development department at its Changwon machine tool plant which undertakes research into new products and systems as well as product design and development work. Approximately 200 people work in this department, of which half work in product research and new product development, and the other half in the

design and modification of existing products and in the improvement of the firm's production and quality control. Due to the firm's extensive international connections, about half of the employees in design and development are foreign; about 60% are Japanese and the remainder West German. Most of the personnel in this department have bachelor's degrees in science or engineering and 20 have post-graduate degrees.

A total of 60 employees work in mechanical engineering-based R&D; of these 35 are involved in machine tool and tooling developments and 25 work in a group developing manufacturing systems. Of the 25 engineers and technicians in the systems group, seven are core designers. The group has undertaken two major automation projects. An automated warehousing system, which stores small components and tooling, was designed and built for use in the machine tool plant. These items are loaded into the system and retrieved by a basic materials handling robotic arm, which was also designed and developed internally as part of the project. The other project focused on the installation of an FMS, again in the machine tool plant, to undertake machining work on machine tool components. The system is made up of eight machining centres. The mechanical design and planning work for this system was undertaken by Firm C, but the controls for the system were developed and fitted by Fanuc. The automated warehousing system and the FMS have subsequently been linked, by extending the range of the guided vehicles used in the FMS. In 1985, the development group was enlarging this FMS to 16 machines and it was anticipated that all the design and development work for this system expansion would be undertaken internally.

Both these projects were directed at improving and automating the firm's production facilities, but it was anticipated that the experience they had gained through these projects would be used in the future in sales of automated systems on the Korean market. The systems group has also developed automated features which are included as options on its CNC machines and are available on the domestic market. On the firm's slant bed lathe, a simple pneumatic robot arm which can load and unload workpieces is available. On the horizontal machining centres, the automated features which may be added are rotary tables - which enable

machining on several of the workpiece surfaces to be undertaken in one set up - and a pallet set or pallet pool - which enables the machine to automatically load and unload components already set up on pallets and thus run unmanned. The development of these automated features was not undertaken entirely by Firm C, as technology and specifications from the firm's German subsidiary have been used.

A simple control unit designed by a group of 40 of ^{the} employees in the development department was put on the Korean domestic market, attached to machines built by Firm C, in early 1985. The controls group is made up of 10 Koreans and 30 Japanese; all the Japanese engineers had considerable expertise in microelectronics techniques before they joined Firm C. In total, the group had spent two and a half years designing, building, and testing this control unit. The control unit cannot be compared to those which are available from Fanuc or from other commercial control producers; firstly, the firm estimated that its controls technology was about ten years behind that of the market leaders and, secondly, the control could only be used on lathes or basic milling machines (i.e., it cannot control more than 2½ axes). (The market viability of this control unit is discussed in Section 6.7.)

Obviously, this firm has a very high level of knowledge of the technology behind the production and operation of machine tools, automated manufacturing systems, and control units which has enabled it to develop the systems described above. These capabilities were principally acquired through the recruitment of foreign personnel, who had already been trained in their countries of origin. However, the extent to which these capabilities are being transferred to Korean nationals is uncertain. Nor is it likely that any other Korean firm will be able to follow the example of Firm C in recruiting such large numbers of foreign specialists.

6.5 Learning Methods Used by the Sample Firms

An important feature of the acquisition of capabilities by the sample firms is the very wide range of learning methods which have been used. Learning by searching - obtaining information and specifications of other firms' products - and learning by using - installing one or more CNC machines in the firm - were methods used by several firms to learn about the principles of CNC machine tool design and to build up information on their operating parameters before commencing CNC development. Some firms bought in new technology by entering licensing agreements. Other firms copied imported machines, and learnt the principles behind their operation by reproducing and modifying them. Firms also used various learning methods to acquire tacit knowledge: learning by training - sending their own personnel to established plants to learn different skills - and learning by hiring - employing foreign experts to work in their production plant in order to train their personnel and sort out problematic areas - to improve the technological capabilities of their employees. Often these two learning methods were incorporated in licensing agreements, but other arrangements for these types of learning were instituted by the firms themselves and through special government schemes. In one case (Firm E), a co-production agreement with a Japanese firm was negotiated, which involved the Korean firm undertaking mechanical design work in collaboration with the Japanese firm. Through this project, the Korean firm improved its design capabilities using the method described as learning by supplying. Finally, one firm (C) increased its levels of technological abilities through a very unusual method for a NIC firm, by taking over established producers in an industrialised country. The acquisition of these foreign companies gave Firm C access to the designs of complete product ranges and the support of a well-established and experienced core design team.

There were three basic methods used by firms to acquire their first design of a CNC machine tool: firms either entered a licensing agreement with an established foreign producer, entered a collaborative development project with KIST, or developed the model themselves. Entrants using this last method either adapted an existing production model by retro-fitting

controls to it or copied a CNC machine to which they had access. All these methods of entry were used with equal frequency by the sample firms. To further expand or improve their capabilities and to develop new models, several firms used a succession of licensing agreements or entered new collaborative projects with KIST. None of the firms has been isolated from outside support, as all the firms have either used a licensing agreement, or collaborated with KIST, or did both at some stage of their development. In the acquisition of interfacing skills, most firms took advantage of training schemes offered by Fanuc; other sources of support in this technology came from KIST and through licensing agreements. Production skills were enhanced and improved through information contained in licensing agreements and from the visits of Korean engineers to foreign firms and foreign engineers to Korean firms. Capabilities in R&D have been acquired by the usual patterns of employment, including the recruitment of qualified personnel from abroad.

Three particular methods of technology acquisition and enhancement need to be discussed in more detail in order to understand their relative effectiveness and importance in firms' development: viz., licensing agreements, collaborative development projects with KIST and the transfer of personnel in order to build up skills.

Utilisation of Licensing Agreements

Seven of the nine sample firms had entered licensing agreements for CNC machines at some stage in their development. In three of these cases, firms used licensing agreements to provide the design for their initial entry into CNC machine tool production. Table 6.6 lists the licensing agreements entered by the firms, the types of machines covered by these agreements, and the licensor.

Only two sample firms (H and I) had not at some stage in their development entered a licensing agreement; both of these firms were small independent companies, and neither of them had yet made such agreements because of difficulties, with only the limited resources of a small company, in finding a potential licensor. In interviews, personnel in both

firms stated that they wished to enter licensing agreements in the future to develop new CNC machines: in the case of Firm H, a machining centre, and a more complex lathe in the case of Firm I. Firm I has more recently been able to build up close links with an American-Korean joint venture company and hopes to license a lathe from the American partner. For Firm H, the problem of finding a licensor remains great, especially as the managing director, for political reasons noted above, did not want to enter an agreement with a Japanese licensor.

Table 6.6 Licensing Agreements Entered by Sample Firms

Firm	Year	Type of Machine	Licensor ^a
A	1984	Machining Centre	Japan
		Hobbing Machine	Japan
		Special Purpose Machines	Japan
B	1976	Conventional Lathe	
	1977	Tool Grinder	Makino, Japan
	1977	Boring Machine	Ikega, Japan
	1980	Machining Centre (Horiz.)	Mitsu-Seiki, Japan
	1983	Machining Centre (Horiz.) ^b	Toshiba, Japan
	1983	Machining Centre (Vert.)	Chiron-Werke, FRG
C	1981	Machining Centre (Vert.)	Yasuda, Japan
	1984	Machining Centre	Nanderer, FRG
D	1977	Milling Machine (Conventional)	Hitachi-Seiki, Japan
	1983	Machining Centre	Hitachi-Seiki, Japan
	1983	Turning Centre	
E	-	Lathe and CNC Lathe	Yamazaki, Japan
	-	Milling Machine	Hitachi Seiko, Japan
	-	Boring and Milling Machine	Toshiba, Japan
F	1977	CNC Lathe	Japan
	1978	Surface Grinder	Japan
G	1975	Milling Machine	Sihtuoka, Japan

a, In some cases only the country of the licensor was revealed.

b, Co-production agreement to be re-negotiated to a licensing agreement.

Source: Firm Data.

The majority of the licences used were with Japanese firms, and only in two of the later agreements (in 1983 and 1984) were West German licensors used. As Japan has dominated the market and technology of small standard conventional and CNC machine tools for many years, it was the main source of technology in the sector of the market into which the Korean firms were entering and the obvious first source of technology. In this reliance on Japan as the main source of technology agreements, the Korean machine tool industry follows the example of many other Korean industries which acquired the majority of their new technology from Japan (see Chapter 5).

Of the ten licensing agreements for CNC machine tools, three were for lathes and the remainder were all for machining centres. It should be noted that the two largest machining centre manufacturers (B and C) entered new licensing agreements in order to expand their range of products and to learn more about the design of these machines rather than to develop their own designs. In contrast, there were no cases of re-licensing in the development of new CNC lathes. This bias towards the licensing of machining centres may be explained by the far greater difficulties in designing complex machining centres than simpler CNC lathes. There were no formal agreements for the transfer of designs for CNC milling machines, although Firm G did receive help from the licensors of their milling machine in the design and development of a CNC version. This firm has a very low design capability compared to the other CNC milling machine producers. Other producers all had the capabilities to retro-fit existing milling machines and found it relatively easy to develop their own models, or, as in the case of Firm H, to collaborate with KIST.

As well as procuring the design of machine tools in these agreements, many of the licensees noted some of the other technological capabilities that were passed on through licensing agreements. The case of Firm A shows how one firm insisted on getting more than the design and production method of the machine: considerable skill levels were also built up by the training of design and other personnel from the Korean firm at the licensor's own plant. The transfer of interfacing know-how

was another important component of the technological contents of the licences, helping firms to develop their own electronics capabilities. As well as acquiring the design of a machine which was known to have been successful, firms obtained many other benefits, including an improvement in quality and an increase in the overall technological capabilities of their own personnel. Importantly, enhancements in production technology and skills were utilised in the manufacture of all the firm's products. Such benefits were probably as important to the subsequent development of the firm as any increase in design capabilities. One firm in particular (F) observed that the quality of its output was considerably improved by the agreement they entered in 1977, even though it only produced a few machines under this agreement.

Only three firms licensed a CNC machine tool for their first CNC production. The other firms first experimented with the design and development of CNC machine tools before entering licensing agreements. The development of CNC capabilities in Firms D and F in particular shows how firms used licensing agreements only after the establishment of some CNC production. Initially, these firms tried to develop new machines in their own design departments and collaborated with KIST researchers. Although several models of CNC machines were developed, and a few machines were sold, in both cases firms' entries into CNC production were not particularly successful. Having established some basic knowledge in the design and operation of this new type of product, the firms entered into licensing agreements in order to improve their products. The two firms then utilised the knowledge they had gained through the licensing agreement to develop new machines. Following its licensing agreement, Firm F developed other CNC lathes, including one of complex design, while Firm D used the increase in its capabilities to alter and improve the design of the machining centre it had produced earlier in collaboration with KIST. The initial base of knowledge acquired by these two firms was particularly important to subsequent development. The firms were aware of the areas of machine design and production in which they had difficulties, and these skills were effectively acquired through the licence. These two firms, therefore, had initially established a base of

technical knowledge on which new foreign technology was quickly assimilated and utilised in the design of other products.

In some of the firms, close relationships were set up with the licensors which continued through successive licensing agreements for other types of machines. Furthermore, these relationships were used when the Korean firms wished to consult with the licensors on the design of new products developed in the Korean firms. These links were especially strong in one firm (G) which had a very weak design department. This firm continued to consult with its Japanese licensor when it wanted to alter designs or manufacture new products.

The Role of KIST, KIMM, and the SMIPC

The five collaborative projects entered into by the Precision Machining Group at KIST with the sample firms are listed in Table 6.7, which also shows the types of machines developed and the dates of the projects. In three cases (F, I and H), firms collaborated with KIST to develop their first CNC machine tool. And in the case of two of these firms (I and H), this has been the only outside technical help they have had in CNC development, as neither of these firms have negotiated licensing agreements. Firm F subsequently entered a licensing agreement, but has used the machines it developed with KIST in its own factory for many years.

Table 6.7 Collaborative Projects with KIST

Firm	Year	Project
F	1976	CNC Lathe
I	1978-79	CNC Lathe
H	1981	CNC Milling Machine
E	1982-83	Machining Centre
D	1983	Machining Centre

Source: Firm data.

The other two projects (in collaboration with Firms D and E) were both for the development of machining centres. Both of these firms had already developed and produced CNC milling machines and were anxious to expand their product range. However, neither of the machining centres developed in these projects was successful. Firm D subsequently entered a licensing agreement for the production of a machining centre, and, using this experience, improved the design of the machining centre developed with KIST. Firm E was unable to find a market for its machining centre, and thus did not produce the machine commercially.

Between 1976 and 1983, KIST was an important source of technical support for the sample firms, not only through the collaborative projects listed above but through the training and introductory courses to CNC technology that it ran. KIST not only helped firms in design but was an important source of interfacing training and advice. (KIST engineers were trained by Fanuc during KIST's first CNC project). Chapter 5 discussed the reorganisation of the government-supported research institutes in 1981. Following this reorganisation, the researchers in the Precision Machining Group were transferred to the new development centre at KIMM in Changwon. However, only a few of the researchers remained at KIMM; some started their own businesses while others went to work in the research departments of various *chaebol* and technical departments in Korean universities. The head of the group went to work in a university in Taejon, and in this position continued to advise Firm H. However, in 1985 he left Korea to work for a Japanese company. KAIST has maintained some interest in machine tool and manufacturing technology, but this is principally in the fields of FMS and robotics development. Both these areas are far removed from the type of technical support the majority of the sample firms need.

As the NC centre at KIMM was established only in early 1983, the centre was not involved in the development of CNC machine tools in any of the nine firms. Furthermore, there seem to have been no significant links between sample firms and the centre since its inception. One firm (A) mentioned that KIMM had advised on the design of a standard machine tool and Firm F hoped to undertake a specific project with KIMM to develop a

high-precision spindle head. The main links that have been built up between the firms and KIMM derive from KIMM's testing and inspection functions. Most firms noted that for their machines to be approved they had to liaise with KIMM, and advice on improvements they received in this process was useful to them. Many of the firms' technical staff from the firms also attended seminars on CNC and general machine tool technology at KIMM.

The larger firms felt they had greater internal capabilities than those available at KIMM, and, therefore, would not enter collaborative projects with this institute. This was particularly noted by Firm A, where the interviewee acknowledged that KIMM did advise on standard machine tool design, but since they have no experience in the design of special purpose machine tools, they were unable to help in the firm's main product/design area. The firm also considered that it had developed faster than the research institutes and for that reason received little help from them. The R&D resources of Firms B and C were, indeed, both technically far more advanced than KIMM. Firm B, however, recruited many research students from KAIST to work in its own research centre. Firm F was the only large producer to suggest a possible collaborative project, but this was in the development of a specific component and not for the development of an entire new machine.

While the large producers have become technologically self-reliant, the small independent producers do not have the same resources, and, for this type of firm, the KIST research group was a particularly important source of technical support. Following the reorganisation of 1981, these firms were therefore left without technical support. However, in the last few years the small and medium firms have received technical help in the design and interfacing of new machines through the SMIPC. Through this organisation, firms have not only been able to collaborate with technical personnel employed by the SMIPC, but through a special scheme some firms have been given grants to employ foreign specialists to help with design and production problems. The SMIPC also runs courses in CNC machine tool operation, which prove beneficial both to the prospective CNC entrants and to the growing number of small firms which are acquiring CNC machines.

The Transfer of Technological Capabilities by the Transfer and Training
of Personnel

An important finding emerging from this study is that firms acquired many technological capabilities, or improved existing capabilities, through the direct training of their personnel by skilled and experienced employees in other firms and institutes. Such transfer and training of personnel was undertaken on both formal and informal levels, and with both other producers and users. Formal transfer of these skills came through the on-site training of personnel included in the details of some licensing agreements and the employment of consultants to "trouble shoot" and advise in Korean plants. Informal transfers occurred, for example, when links were maintained with former licensors who continued to advise Korean firms in their subsequent product developments, or when, as in the case of Firm I, American engineers from a local joint-venture company gave technical advice.

Table 6.8 below gives details of each firm's use of this technology transfer method. (The transfer of interfacing skills from Fanuc, and sometimes from KIST, has not been included as this occurred in nearly all the firms.) Additionally, it should be noted that KIMM has also received help and advice from several leading researchers into machine tool technology from overseas. During these visits, the researchers advised KIMM on its work, gave seminars for the research staff at KIMM and local industrialists, and visited and advised local firms.

Amongst the firms, there are examples of this kind of technology transfer in all four types of skill considered. One area which particularly benefitted was production, where skills were transferred both by personnel working and visiting in other plants and by visiting specialists to the Korean plants. Benefits from improvements in production techniques were two-fold: firstly, Korean producers were able to raise the quality of the machines they were manufacturing, and, secondly, they were able to improve their productivity. To a certain extent, firms were also able to build up their own skills in this area

through the operation of imported CNC machine tools, though the transfer of personnel has proved more effective.

Table 6.8 Acquisition of Capabilities by Transfer and Training of Personnel in the Sample Firms

<u>Firm</u>	<u>Capabilities Gained and Method of Transfer</u>
A	Most of the personnel in the design department have been trained either in Japan or the US. Many engineers sent to licensor's plant in Japan for between three and six months to undertake training, included in the licensing agreement.
B	Japanese engineers consulted with designers in Firm B as part of co-production agreement to develop a machining centre. Several researchers in laser technology sent to the US for training in both plants and universities.
C	Large number of foreign engineers working in Korean plant, transferring some of their knowledge to Korean workers. Many Korean employees have also been trained in Japan, the US and West Germany.
D	Approximately 10 of the 40 engineers in the design department have undertaken some training in Japan and employees from Japanese licensor trained personnel in Korean plant. The firm has also maintained close advisory links with its former licensor.
E	Close advisory links with former licensor have been maintained. Korean firm undertook design work in co-production agreement with Japanese firm. One member of staff was trained in Japan.
F	Firm sent personnel to Japan and the US for training. Production engineering and quality control both important aspects of this training, as well as acquisition of new technology.
G	Co-production agreement with Japanese firm which included several Koreans being trained at the Japanese factory and Japanese engineer working in the Korean plant.
H	Two members of the design staff had some training in Japan.
I	Technical advice in production from American engineers working at a separate joint-venture company. Engineers and technicians in the firm were given some training by a visiting foreign consultant, whose visit was subsidised by the SMIPC.

Source: Firm Data

A high proportion of this type of technical transfer occurred as part of the numerous licensing agreements Korean firms entered into: Firms A, D, E, F and G, for example, all received training as part of their licensing agreements. The collaborative work in the co-production

agreements entered by Firms B and E also resulted in similar transfers of knowledge. In this field, Firm A was the most aggressive: in interview, a technical director stated that the firm always adds conditions for engineers to be trained by the licensor whenever they buy in technology.

Rather suprisingly, many firms were able to maintain close advisory links with former licensors, and through these links continued to obtain advice on new product designs and interfaces, and on problems in production and quality control. The reasons for licensors to allow these links to continue are difficult to comprehend as they are no longer receiving any financial benefit from giving this advice and they are helping possible future competitors to develop more rapidly. Von Hippel, however, suggests that in general, exchange of information in business enterprises may proceed along informal channels constituted by personnel with similar technical interests and may not involve strategic business deliberations (Von Hippel, 1987: 292)

Obviously, the greatest technical asset of Firm C has been its ability to employ a very large number of highly qualified and experienced engineers. For other firms, employment of foreigners on this scale would prove very difficult. The *chaebol* firms which do have extensive links abroad are able to employ consultants or send personnel abroad for specific problems, but none of them have directly employed overseas experts on a permanent basis. While the small firms have also obtained help and advice from foreigners, for them the investment in such services is costly and, consequently, are often regarded as an unaffordable luxury. For these firms, the SMIPC has instituted a scheme which subsidises visits of foreign consultants and which has made this source a more feasible proposition for small firms.

In a similar fashion, the technological inter-firm linkages between producers and users have also been important to the sample firms' overall learning process. Although in these cases new technology was not necessarily transferred, an enhancement of existing technological capabilities did occur. This was the result of a build up of knowledge of the operating parameters of machinery and an awareness of both

potential problems and improvements. In this study the main examples of this type of learning come from the interaction between machine tool and vehicle producers. In the cases of Firms A and D, such links were automatically created as they were an integral part of vehicle production within their respective *chaebol*. However, other firms, including B, C and F, have built up close links with vehicle and vehicle components producers with similar effect. Two other user industries, mould producers and electronics manufacturers, have also been important in this type of learning process. In both these cases, the user industry provided the main motivation for machine tool producers to expand their production ranges and, as such, were an important spur to new technological developments.

The general significance of personnel movement and on-site training in technological transfer, and of interactive learning in capability enhancement, must be underlined. Such direct methods of technology acquisition are particularly important and effective when the skills concerned are mainly or partly tacit in character. That is, certain skills and capabilities cannot be easily formalised and incorporated in explicit written directions. Indeed, the importance of tacit knowledge is very great in many areas of engineering know-how. The depth of knowledge that can be gained by watching others do things cannot in many cases be secured through a set of instructions or blueprints, however explicit and detailed.

6.6 Made in Korea? The Indigenous Content of Korean CNC Machine Tools

Earlier chapters described and explained the reduction in vertical integration in the production of CNC compared to conventional machine tool manufacturing. For Korean producers, the majority of the components required for CNC machine tool production have to be imported. Combined, these components have a high value and account for a large proportion of the final cost of the machine. This section examines the low indigenous content of CNC machine tools manufactured by sample firms and discusses the implications of firms' reliance on foreign components supplies. As the lack of indigenous production of these critical components has been noted as a major constraint on the development of an indigenous CNC machine tool industry, this section also considers Korea's entry into the production of components. Because the control unit alone is such a high-cost component, and because of its importance to the production of CNC machine tools, the relationship between sample firms and controls producers is discussed separately in the next section, where attempts by various Korean firms to enter production of control units are also documented.

Respondents to questionnaires were asked roughly to break down the total CNC machine cost into seven categories: viz., the costs of the control unit, other components, raw materials, subcontracted work, factory overheads and labour, combined design, development and research expenditure, and, where applicable, payment of royalties. Typical examples of these breakdowns for different types of machines covered are shown in Table 6.9.

Table 6.9 Breakdown of CNC Machine Tool Cost (expressed as % of total costs)

Cost Component	Type of Machine				
	Machining Centre (A)*	Machining Centre (C)	CNC Mill (F)	CNC Mill (H)	CNC Lathe (B)
Control Unit	20	30	33	30	46
Other Components	5	20	22	15	22
Raw Materials	30	15	5	10	9
Subcontracted Work	5	5	0	20	2
Royalties	3	N/A	N/A	N/A	N/A
Factory overheads and labour costs	30	5	40	20	21
Design, development and research costs	7	15	0	5	0

a. Letters designate producing firm.

Source: Firm Data

This table shows that for the Korean producers a very high percentage of the final cost of the machines manufactured is accounted for by bought-in components: the control unit, other components, and raw materials. Over the whole sample of firms, the proportional cost of these three outlays accounted for between 55% and 86% of the total machine cost. In all cases where royalties were payable, they were set at 3%, the maximum value permitted through Korean legislation at the time. As Korea does not yet have a network of specialist suppliers, a very high proportion of the components which firms have to purchase also have to be imported. Table 6.10 lists all the major components purchased by the machine tool builders, divided into two categories: imported and domestically produced.

Table 6.10 Major Imported and Domestically Produced Components

Exclusively or Mainly Imported Components	Exclusively or Mainly Domestically Produced Components
CNC Control	Castings
Ball Screw	Forgings
D.C. Servo-Motor	Some Bearings
Spindle Motors	Chucks
High Pressure Pipes	Gauges
Lubricants	Tools
Special Bearings (including Angular Contact Bearings and High Precision Bearings)	Lubricant Tanks and Filters
Valves	Shafts
Sensors	Blocks
Couplings	Piping Materials
Hydraulic Units	Relays
Power Belts	Electric Cables
Some Special Gears	Gears
	Other Small Machined Parts

Source: Firm Data and Interviews

This table shows that all the high precision, technically complex and expensive components tend to be imported, while those with a relatively low technical content are domestically supplied. This is the case for both electrical and mechanical components. For most Korean producers, imported materials and components account for at least 40% of the final cost. Consequently, only a low proportion of the final CNC machine tool cost is made up of labour costs, either directly in the firm or indirectly through the production of components in Korea. Low labour costs, the major traditional basis of Korea's competitive advantage in international markets, therefore cannot contribute significantly to make Korea's CNC machine tools cheaper than those produced in higher wage countries.

The high value and importance of imported components create further disadvantages for Korean producers compared to manufacturers in countries where these supporting suppliers are locally sourced. Firstly, the barrier to entry of having to establish contact with potential suppliers must be overcome in order to purchase the required parts. Korean firms buy most of their imported components from suppliers in Japan. The proximity of the two countries, and the widespread knowledge of the

Japanese language amongst Koreans, have made it relatively easy for Koreans to visit suppliers and discuss their requirements in detail. As Japan is now the leading producer of CNC machine tools and has a thriving components industry, this is the best source for the components that Korean producers need to buy. Although Korean producers have an advantage over more remote industries such as India's, through their close proximity to a supplier nation, nevertheless, the Korean industry is still at a disadvantage compared to those which can source components domestically: the time delay in securing components can still be a serious problem.

The second major disadvantage for Korean producers is the high cost of imported components. Few Korean firms manufacture CNC machine tools in such numbers that they can obtain quantity discounts from suppliers: this applies to all types of components, including the control unit. Thus, the components they import are very expensive compared to the price paid by large-scale Japanese producers. In particular, all the firms stressed that the price they paid for control units was very high compared to the price paid by most Japanese producers. Jacobsson's analysis of possible price reductions in components available to large manufacturers which buy in bulk suggests that the total cost of raw materials and components may be reduced by as much as 22% (1983: 200). In total machine tool cost, this size of discount can give the large producers a 10% price advantage over small producers. Jacobsson also claims (1983: 199) in the case of one Korean producer (Firm B in this study) that this firm obtained significant discounts in the purchase of control units from Fanuc. However, interviews conducted in the course of this study cannot confirm this claim.

Furthermore, the lack of a local network of specialist small firms also means that very little of the basic machining work or part assembly production is subcontracted by the sample firms. In general, the proportion of total cost deriving from subcontracted work was less than 5%. In countries with a highly developed subcontracting system, producers are able to reduce production costs by subcontracting this type of work.

Reliance upon imported components and low levels of subcontracting stem from the same problem, viz., the poor development of small specialist firms. In the early 1980s, many Korean economists attributed the relatively slow development of small and medium firms to the government's earlier policy bias towards the heavy machinery and chemical industries and the *chaebol*.⁸ They also suggested that Korea may never develop a network of small firms in this area. A "vicious circle" was identified which was allegedly deterring development of new subcontracting firms: as subcontracting was poorly developed, firms were discouraged from specialising, and, by not specialising, the establishment of a subcontracting network was further retarded. In Amsden and Kim's study, this vicious circle was identified in the general machinery industry (1986: 118-20). Their main evidence was that investment in new plant and equipment by small and medium firms in this sector, and their expenditure on R&D, accounted for only a small proportion of national levels compared to their total share of the nation's employment and value added. However, they also suggested other reasons for the retardation of these types of firms. Firstly, they argued that subcontracting is typically undertaken by many small firms clustered around large production units, but, as the latter have only recently commenced manufacturing, the demand for subcontractors is also a recent phenomenon. Secondly, they suggested that subcontracting flourishes when large production units are unable to cope with excess demand. But in Korea many of the large production units continue to operate at less than full capacity, so there is little work available for subcontractors to undertake.⁹ Nevertheless, they concluded that with the maintenance of the government's defence-related support and over-capacity in this industry, specialisation and subcontracting would continue to be discouraged.

Although at the time of this study the indigenous content of the machines being produced was low, there were then signs that Korea was beginning to develop its components industry and that a network of specialist producers and subcontracting firms was evolving. One of the sample firms (C) commenced production of a small range of ball screws in early 1985 and was planning to copy its imported precision screw cutting machine in order to increase their output of this component. Although

the lead screw thread and nut were being machined in Firm C's plant and the finished components were being assembled in a special clean room, the firm was still importing the precision ground steel balls used in the rolling mechanism.

Another firm (B) had also begun to subcontract a large proportion of its machining and assembly work. This firm had ceased its own manufacture of some conventional machines and subcontracted their production to smaller independent firms. Moreover, it has been shown earlier that many of the *chaebol* are building up their own networks of subcontractors. For example, a large market for Firm A's machine tools are the subcontractors which undertake work on vehicle components for its car production.

In 1985, a national plan to indigenise the production of certain machine tool components was also published. Under this plan, KOMMA announced that domestic firms would be "encouraged" to develop key components of machine tools (Korea Economic Daily, 19 May 1985).¹⁰ The Association had government backing for the plan through the Ministry of Commerce and Industry. The plan designated one or more firms to develop and produce ten different types of component. Significantly, the majority of the firms nominated were medium-sized companies already producing components, and only a few *chaebol* and machine tool producers were chosen. The listed parts were: hydraulic valves, cylinders, motors and chucks, steel balls, servo-motors, hydraulic terminal blocks, solenoid valves, pneumatic equipment, and safety equipment. Ball screws were not on the list since limited production had already commenced, but the steel balls which were being imported for their construction were included. It should also be noted that the control unit was not included on this list. The most technically complex part included in the plan is the servo-motor, and for its production two *chaebols* in the case study (B and C) were nominated. While in the case of C the motors will probably be produced by the machine tool division, in B it is highly likely that the motors will be made by another division of the *chaebol*, which specialises in electric motor manufacture. Other machine tool firms nominated to

produce various parts were: Firm F for the production of hydraulic chucks, and a non-CNC producer for the production of hydraulic terminal blocks.

Consequently, this study does not support Amsden and Kim's conclusion that the general machinery industry has become stuck in a vicious circle inhibiting the development of specialist firms. The problem of a lack of small specialist firms may in reality only be a transitory one for Korea's machine tool industry. It is quite plausible that the production of components will only begin in earnest when there is sufficient local demand, and thus the establishment of small specialist firms depends on the prior build up of machine tool production. It should not be expected to precede the development of this industry nor to commence at the same time as its major user. Just as backward integration into machinery production, discussed in Chapter 2, is widely seen as a "natural" progression from manufacturing production, so the development of specialist components producers and subcontractors should also be thought of as a backward integration of the establishment of a machinery industry.

6.7 The Sourcing of Control Units and Korean Attempts at Controls

Production

Amongst components and parts bought in by machine tool producers, the most expensive by far is the control unit. Table 6.9 shows that the proportion of total machine cost accounted for by the control unit ranged from 20% to 46%. This proportional cost varies significantly and is dependent on the type and complexity of the machines produced. In general, the cost of the control unit is relatively constant, so the cheaper the machine is to produce, the higher the proportional cost of the control unit. A lathe is the simplest and cheapest machine. It has just one slide to be machined, and, since it has only two controlled axes, it requires a small number of servo-motors. Thus, the proportional cost of the control unit in a lathe is relatively high. By comparison, a milling machine with 2½-axis control has more moving parts and three machined slides; consequently, its construction requires more machining and assembly work, as well as more servo-motors. Accordingly, the proportional cost of its control unit is lower. Again, a machining centre has even more complex mechanical parts and additional manufactured units, such as the ATC, making the proportional cost of its control unit lower still.¹¹

The main supplier of control units to the Korean CNC producers is Fanuc, and this company has been important in the training of Korean personnel in interfacing skills. The first entrants obtained control units direct from Fanuc in Japan, and Korean technicians, including several researchers from KIST, undertook CNC courses at Fanuc's Japanese plant. One early change in the relationship between the Korean machine tool industry and Fanuc was the establishment by Fanuc and Firm F of a joint-venture company, Korea Numeric Corporation (KNC), in 1978. Firm F entered this joint-venture company with the intention of establishing very close relations with Fanuc and developing new products with them. At the foundation of KNC, Firm F had a 51% holding and Fanuc held the remaining 49%. However, Firm F soon realised that it was not receiving any of the anticipated technical or financial benefits from being part of the joint-venture, and has since sold the majority of its holding to

another Korean *chaebol*, retaining only a 7% holding. Despite its sale of most of its holding in KNC, Firm F has maintained fairly close links with KNC. The purchasing *chaebol* does not have any interest in the production of machine tools, but it does have a separate agreement with Fanuc to assemble, sell, and, eventually, to manufacture robots (Korea Herald, 2 June 1985).

KNC has four areas of business interest in Korea, namely, assembly and sales of CNC control units, assembly and sales of mechatronics products (electro-discharge machines and robots), cable winding, and repairs and maintenance services for Fanuc products. The share of income derived from each of these areas is shown in Table 6.11

Table 6.11 KNC's Income from Different Divisions

Division	Percentage Share of Total Income from Division
Controls	38
Mechatronics Products	30
Cable Production	25
Repairs and Maintenance	7

Source: Firm data

In total, 90 people are employed by KNC, of which three are Japanese and hold managerial positions; the remainder are all Korean. Of the Korean employees, approximately 50 are women employed on cable winding. This work is the simple manual task of winding different wires and cables onto various looms. Most of the cables are shipped to Fanuc in Japan. Eight people are employed to undertake repairs and maintenance work. These services are arranged by Fanuc (in Japan) and Fanuc pay KNC for the work done. The remaining employees are in the two assembly areas. For this work, all parts and components are supplied by Fanuc and assembled in the Korean plant, but the actual assembly work performed is very limited. At the time of the interview, there were no plans to localise the production of any of the parts or components used, although it was suggested that if demand did increase substantially some parts may be produced locally. All of the CNC control units, machines, and robots

produced at KNC are for the domestic market. Part of the work of the CNC division is to assist and advise machine tool producers in Korea who are developing CNC machines; it will advise on the choice of control unit and motors, as well as on the general specifications of the machine.

The establishment of this joint venture was considered beneficial to the existing CNC producers and to new entrants. Firstly, the domestic location of a supplier reduced firms' waiting times for required parts. Secondly, the domestic availability of a repair and maintenance facility helped the sales of CNC machine tools on the domestic market, as users no longer ran the risk of long down-times following a machine breakdown. Thirdly, the advice and training available through this joint venture considerably eased the cost and time involved in sending personnel to Japan for training. In addition, the availability of local advice has meant that producers can more easily discuss specifications of new products and adaptations with personnel at KNC, rather than having to deal with these over a distance. However, there has been no advantage to the Korean producers in the field of controls technology, since production was limited to very basic assembly work and all parts were imported. Consequently, Fanuc has managed to keep its "black box" firmly shut.

Korean Attempts at Control Unit Production

While Firm F tried to increase its expertise in control units through establishing a joint venture with Fanuc, there have been two other attempts by firms to enter the production of controls units independently. In 1980, a project to develop a control unit in the Department of Industrial Electronics at KIST was initiated and funded by Firm B.¹² This firm had already gained some experience in the production of CNC machine tools using imported (Fanuc) controls, but it was becoming especially apprehensive about potential increases in the price of imported controls. This would make its CNC machines less competitive on export markets, and anxiety about this possibility constituted a primary reason for its interest in the indigenous production of controls. Seven students, all with electrical/electronics backgrounds, worked on the project, four of whom had originally been employed at Firm B's production

plant. To familiarise themselves with the problems and technology of machine tools control, the students all spent three months at the Changwon plant learning how to operate CNC machines.

The development of the control unit took about two years, during which time a working proto-type designed to control a lathe was built. In 1981, three master's dissertations were submitted by researchers who had been working on the project. These looked at the system design and software, the servo-controller, and the manual data input and display system (KAIST, 1981: 101). The project developed a differential analyser, hardwired interpolator, servo-controller, and related software and hardware. The hardware used three Motorola microprocessors, while memory was mostly on ROMs. For the interpolator and software algorithms, RAMs could have been used, but as the technology was still at an experimental stage, and the most important consideration for the research team was that the proto-type should be reliable and satisfy the original specification, the researchers decided to use the more reliable ROM technology. While the microprocessor technology did not cause any problems, the differential analyser was very difficult to design. In the final prototype, the differential analyser consisted of about 200 small circuit boards.

In 1982, the division to which Firm B belongs was re-structured and a technical centre for the division was established at Inchon (the R&D work undertaken at this centre was discussed earlier). With this change in location of R&D, and a change in technology policy in the division, the controls project was dropped. The researchers from the project remained in the employment of the heavy engineering division of *Chaebol B*, and all went to work at the new R&D centre at Inchon.

While CNC control units have not been subsequently experimented with at the research centre at Inchon, other forms of controls technology have been developed by the original researchers from the KIST controls project. As noted earlier, two types of laser machines have been developed by this centre and they are both controlled by a basic two-dimensional control unit designed and built by the research centre.

A separate group within the research centre works on robot design and development, and, again, the centre developed its own control unit for the robot they produced. This unit controls five axes of movement on the robot, and a sixth axis can be added by the firm if the client requires it. The controller can also be connected to various sensory devices, including visual sensors (Korean Business Review, Sept. 1985: 66).

Following the joint project between KIST and Firm B, the Department of Industrial Electronics continued with the same type of work, but no further work on machine tool controls has since been undertaken. In 1980, a simple point-to-point control was developed with an electronics company; this control was for a machine which automatically inserted printed circuit boards. Subsequently, a continuous^u path controller was developed, and research on robot control has been undertaken. A few of the controls researchers moved to the Numerical Control Centre at KIMM, but most of their work there has centred on robotics and software development.

One other firm (C) has produced a control unit. This was, however, a very new development in 1985 and only a few had been fitted to basic CNC milling machines which were solely for sale on the domestic market. These units were not to be sold to other machine tool producers, and the firm had no intention of becoming a controls unit supplier. As described earlier, this control unit was developed within the firm principally by Japanese engineers employed on the project. By the firm's own estimate of its technology, this control unit was at least five, and probably ten, years behind the control units being produced by Fanuc at the time. The firm, however, hoped that it would be able to produce them at a lower cost than it had to pay for bought-in components, and would thus be able to compete at the very basic end of the domestic market.

It is difficult to evaluate the future prospects for this control unit on international markets. With continued development to acceptable standards, the firm does have a ready market in its two German subsidiaries. Furthermore, having already established a service network in the US and in Europe for its machine tools, the addition of controls

repairs and maintenance would be fairly easy. With a suitable product, entry into the international market would therefore not be too difficult for this firm. Nevertheless, there are still large technical problems for the Koreans if they are going to develop competitive control units. Moreover, the Korean producer does not yet have adequate technical back-up from the domestic electronics industry. Although Korea is a very large chip producer, there is little design or production of customised or semi-customised chips, the major electronic component of the control unit. The development of a technically competitive product could take the firms many more years. However, the introduction of higher capacity and faster programmable chips may mean that future controls developments will be more dependent on software skills than on electronics design and production skills. Developments such as these would considerably help Korean (and Taiwanese) producers in their controls developments. Even with the production of a competitive control unit, Korean producers would still have some problems introducing them into foreign markets.

Although no other producers were directly engaged in the research and development of a control unit in 1985, there were indications that some manufacturers were looking at alternative controls suppliers to Fanuc. In Firm B some attempts at changing its reliance on Fanuc as its major controls supplier were being undertaken. The firm uses a German control unit on one of its machining centres and in 1983 it entered a co-production agreement with Toshiba for the production of a machining centre utilising Toshiba controls. Through this agreement, the firm was hoping to undertake some of the production work on the control unit and learn about its technology. The firm had found, however, that little of the control unit technology was being transferred and was approaching Toshiba to try to re-negotiate the agreement into a full licensing agreement which would incorporate some rights to technical information on the control unit. Firm I also suggested that in future it may buy controls from the US. The control unit it anticipates using is a modified IBM pc, which is utilised by the American firm with which it was contemplating a licensing agreement. The Korean company would acquire the software and modifications for this system directly from the American firm.

6.8 Conclusions

An adequate understanding of the means and problems of technology acquisition in this area involves considerations usually thought to belong to engineering, to business strategy, and to politics. Nor is it appropriate, except by convention, to treat each element separately. For example, government policy in Korea has directly influenced the business environment for machine tool producers; discussions about entry into technologically complex areas have taken into account government initiatives affecting both machine tool makers and their users; and close business links between producers and their customers have encouraged specific types of technological innovations.

Chapter 3 noted that a range of skills ~~is~~ required to design and manufacture CNC machine tools, and the nature of these skills depends to a great extent on the complexity of the machine being developed. What are these skills, and to what extent have Korean CNC producers successfully mastered them? Analysts of the CNC machine tool industry have considered interfacing skills to be particularly problematic for conventional machine tool firms, because these are not skills used in conventional machine tool production. In fact, the acquisition of these skills was not difficult for the Korean CNC entrants to acquire because of the high levels of technical support offered by controls vendors. Thus, the business strategy of controls suppliers considerably reduced the potential barrier to entry formed by these skills.

The study has shown that experience in the use of conventional machine tools greatly facilitated firms' entry into their construction. Yet the same pattern is not observed in the case of CNC machines. Although several producers bought CNC machines to learn about their operation, they still needed additional help in raising the levels of their production capabilities. In several firms, the initial quality of CNC production was very low. In the main, skills in this area were gained through the training of Korean personnel in foreign plants or the employment of foreign experts in Korean firms. Firms have also had considerable difficulties acquiring design capabilities, and there are

still some gaps in this area. The complexity of the machines being developed appears to have been a major influence on the extent to which design skills have been absorbed. Firms have had little difficulty with the development of either retro-fitted or basic CNC machine tools, but have had serious problems with more complex machines, and especially machining centres.

The mastering of controls production also presents very substantial problems of technological complexity. The electronics and software capabilities required for effective entry to controls production still have not been attained to an adequate level in Korea. Moreover, because the controls business also involves comprehensive repairs and maintenance support, prospective entrants must not only invest heavily in the acquisition of technology but also in the establishment of a network which can offer such support. However, Korean firms have entered the manufacture of less technically complex components used in CNC machine tool production, e.g., the ball screw and, to a lesser extent, servo-motors.

The study has also noted the importance of firms' size and structure. Small firms have had great difficulties acquiring imported technology, largely because they have been unable to negotiate effectively with foreign technology suppliers. The large independent firm (F) did use licensing agreements, and is now widely considered to be the leading problem solver in the Korean industry. This firm has also established close technological inter-firm linkages with manufacturers in several industries. The *chaebol* firms have entered the CNC industry either to manufacture machines for the general market or, specifically, to support their own vehicle manufacturing. In the latter case, products have been directly related to and aimed at their own vehicle production needs. The *chaebol* firms have developed very rapidly; they had the resources to invest in training and the ability to import technology. Importantly, they were able to negotiate effectively for the transfer of technology in licensing agreements. Such firms have also benefitted from facilities available to them through activities within the group. Two firms have had access to design and development support from other parts of the

group. Firms manufacturing for vehicle divisions enjoy very close links with this production area, enabling them to collaborate closely on new developments and to rapidly and automatically receive feedback on their machines.

Most of the sample firms - *chaebol* or independent - have mainly manufactured machine tools for the domestic market, and because of this orientation, firms have been heavily influenced by the specific machinery requirements of Korea's growing manufacturing industries. The Korean government protected the domestic market in areas where indigenous machines were of a satisfactory standard, but the government was careful not to disadvantage users, by allowing them to import machinery if domestically manufactured equivalents were sub-standard. The government also delegated some areas of protection to a para-statal organisation to which both machine tool producers and users belonged. As well as protecting the domestic market, the government gave machine tool producers a range of incentives, including subsidised credit. Whether intentionally or not, it would appear that the government successfully distributed these funds to the firms most able to accumulate technological capabilities rapidly. Most of the loans went to *chaebol* firms, but leading independent companies were also given extensive financial and technical support. Although Korean CNC firms, with government promotion, are building up an export capacity, this has so far been a minor part of the Korean story.

This study also documents the wide variety of learning methods used to acquire technology and to build up capabilities in the design and production of CNC machine tools. The most effective methods have been the use of licensing agreements, design and production support given by KIST, and the transfer of skills by the circulation and interchange of personnel. A notable feature of the learning process followed by several firms was their initial experimentation with the new technology before they entered formal technology agreements. That is to say, they deliberately and effectively "prepared to learn". Firms frequently imported CNC machinery and developed retro-fitted or basic machines, in order to familiarise themselves with their technology and operation.

These firms, therefore, built up a knowledge-base on the technological capability requirements of the product, as well as an assessment of their own abilities, and, importantly, the skills they needed to acquire and the production areas which had proved problematic. The firms also became aware of the high costs and difficulties they would encounter if they continued to try to develop entirely new machines themselves. With this knowledge in hand, firms were able to stipulate the precise terms of agreements and ensure that the particular skills which they needed were transferred. Having prepared to learn, the firms were able to take a very active posture in the negotiation and operation of formal technology transfer agreements.

In their initial CNC developments, several firms were given extensive support by a group of researchers at KIST. As part of the government's 1982 reorganisation of industrial research institutes, KIMM was intended to take over this support function, but this has yet effectively to materialise. For the large *chaebol* producers, the lack of this collaborative option in new developments is not important. These firms have all developed adequate skills in-house, and have the contacts and finances available to undertake their own R&D. For the independent firms, the loss of such technical support could have been catastrophic, especially for the smaller firms which have great difficulties in importing technology. However, the services offered to these firms by the SMIPC appear to have bridged this gap most effectively.

Finally, the study has emphasised the importance of personnel movement, direct training and working contacts in the development of technological capabilities. Such transfers occurred in all capability areas: design, production, interfacing, and R&D. These methods of technology transfer enabled firms to build up capabilities of a tacit nature, which could not be effectively transferred through written instructions or drawings. The directness of contact between machine tool builders and users, especially with firms in the vehicle industry, seems to have been an important mechanism by which skills have been enhanced. Through interactive learning, machine tool producers have been actively engaged with users, have been able to gain a greater understanding of the

special requirements of these firms, and to develop specialised skills to meet their needs. The *chaebol* structure constitutes an environment for the formation and maintenance of these kinds of interaction, though independent firms have also built a network of close inter-firm technological links.

Notes.

1. Jacobsson (1983, 1984, 1985 and 1986) undertook fieldwork in Korea on the CNC lathe industry earlier in the 1980s, and all of the firms used in his study are also covered here. While the present study is more detailed, many of the findings are basically compatible with his work, and, where there is an overlap, points of contact are noted in the discussion passim.
2. Obedience to the government's wishes by the *chaebol* was not entirely an altruistic and nationalistic posture. For example, *Chaebol B* received a considerable number of very large defence contracts, and these may have been put in jeopardy if it had not entered industries which the government wanted to promote. The government, therefore, used "sticks" as well as "carrots" in its promotion of some industries.
3. Most of these foreign workers are "Moonies", and this affiliation is their main motivation for wanting to work for this Korean company.
4. Chatter occurs when the cutting tool vibrates during the cutting process. This results in a very rough uneven edge.
5. There are some very advanced FMSs in which the tooling in the turret may be automatically changed using robotic arms. However, these advanced systems are rare and are not used on stand-alone complex lathes or in FMCs. The design of this sort of tool handling system is therefore not yet a consideration for the Korean producers.
6. Since the NICs only manufacture and sell CNC machine tools in the world market at the lowest end (i.e., the cheapest and most basic types of machines), it may be considered that NIC producers are not direct competitors with the Japanese. Further, as the NICs export few CNC machine tools to Japan, they cannot be seen as competitors to Japanese producers in their most important market. It is therefore questionable whether Fanuc was actually selling to competitors of Japanese CNC producers, or whether, by contrast, it was selling to a different sector of the market.
7. Fanuc offers additional features on its control units which may be utilised by the customer on payment of a higher price. These features include items such as larger memories, "canned cycles" (short programs of frequently used or complex cutting cycles which may be run by a single command, and thereby considerably reduce programming time), and the control of an extra axis. These features may be software- or hardware-dependent and are sometimes built into the control unit but only activated by a Fanuc technician opening the control unit once they have been paid for. Although some firms do open the "black box" in order to use these features, to adapt other features, or to add components, this is strictly against Fanuc's sales contract.

8. See, for example, Kim Jae Won (1983).
9. Amsden and Kim (1986: 119) also comment that in some countries subcontracting is stimulated by differences in wages and employment practices between contractor and contractee. In this field, they note that, as most *chaebol* labour is non-unionised, and wages and conditions are only marginally above those in smaller firms, this motive is weak in Korea.
10. The methods by which the firms would be encouraged was not elaborated in the outline of this plan. However, it is highly likely that the firms would be given a monopoly on domestic production of the listed components for several years, and that the domestic market would be protected to a certain extent.
11. This is not to say that all control units are of the same price, as the price of control units does vary depending on their sophistication and modernity, but this variation in price is much less than the variation in the production costs for manufacturing the different types of machines.
12. The department at KIST involved in this project was the Department of Industrial Electronics. Collaborative projects on the design of CNC machines (discussed in previous sections) were undertaken by a different department at KIST, the Precision Machining Group.

CHAPTER SEVEN

The Development of the Korean Machine Tool Industry in Comparative Perspective: The Cases of Japan and Taiwan

7.1 Introduction

Korea's economic and technological development has not occurred in isolation. Japan has provided a powerful model, while Taiwan has followed a development strategy different from Korea's. Indeed, some writers point to Korea as an imitator of Japan's successful development strategy, and comparisons between Korea and Taiwan form a part of the literature on NIC development.¹ What can be learned by comparing the machine tool industries of Korea, Japan and Taiwan? Is Korea, in fact, following the Japanese model in this area? And is it likely to be able to do so with similar success? How has Japan's prior entry into the machine tool industry, and its current technical and market dominance, influenced Korea's entry? What are the similarities and differences in the development strategies of the two East Asian NICs, Taiwan and Korea? And in particular, what have been the effects of Taiwan's concentration on the export market for machine tools compared to Korea's relatively greater focus on production for domestic consumers?

A major aim of this chapter is to examine how the factors which were influential on the development of the Korean machine tool industry affected the industry in these other two countries. The previous chapter considered four major factors which influenced the build up of technological capabilities in the Korean machine tool industry: the domestic market, promotion of the industry by government, the structure of conglomerate firms (*chaebols*), and the acquisition of foreign technology through licensing agreements, accompanied by learning by hiring and by training. Accordingly, treatment of the Japanese and Taiwanese experiences will focus on the same range of factors. Obviously, certain factors relevant to the experience of some countries will be less relevant to that of others. For example, in Korea's machine tool industry dependence on foreign suppliers of critical components was

important, as it is in Taiwan. However, given the self-sufficiency of the Japanese industry, there is no such dependence.

There is a rich secondary literature on the general patterns of Japanese, and to a lesser extent, Taiwanese industrial development. Indeed, much of that literature is partly concerned with the machinery sector. Since this chapter considers the Japanese experience almost solely as a possible pattern for, and influence on, the Korean machine tool industry, this secondary literature can only be briefly summarised and pointed to in references. The secondary sources are supplemented by data collected during a series of interviews undertaken by the author with several large machine tool producers in Japan and Taiwan in summer 1985. Interviews in Taiwan followed a similar structure to the Korean study, concentrating on sources of technology, acquisition of design capabilities, etc. Interviews in Japan also assessed technological development, the supply of technology and training from Japan to Korean licensees, and Japanese perception of Korea's development.

7.2 Japan: Towards Technology Leadership

The comparison between the Japanese and Korean machine tool industries is not a wholly academic exercise. Korea has been extremely interested in the Japanese experience, and has sought, in many areas, to emulate Japanese development patterns. For example, the important Korean car industry has attempted to copy what it perceives as Japanese structures, especially the development of in-house capabilities to produce machine tools in order to support vehicle production. Similarly, the *chaebol* are building up their own networks of sub-contractors, like those surrounding the *keiretsu*. Nevertheless, Korea has not made a systematic, coherent, and deliberate effort to understand and copy the Japanese experience. The influence of the Japanese model has been largely piecemeal, informal and pragmatic. Korea has recognised very significant differences in its economic environment compared to Japan's. Importantly, Korea's development has been financed by foreign indebtedness, making it the fourth largest debtor nation in the world. Moreover, Korea's domestic market is much smaller than Japan's, with enormous consequences for its production strategies. Korea has had to be much more export orientated

than Japan. As shown earlier, Korea entered some industries, e.g. colour television production, solely for export purposes.

Such structural differences make a point-by-point comparison of Japan and Korea problematic. Most significantly, the economic and technological environment faced by Korean machine tool firms since their entry in the mid-1970s has been fundamentally shaped by the historical fact of Japanese technological and market domination. Following Japan's industry into the world market presents both problems and opportunities. The scale of resources needed to mount a sustained technological challenge to a market dominated by Japan would tax the capacities of even the most dedicated country. On the other hand, following such a successful pioneer - even when it dominates the market to the extent Japan does - makes learning easier and allows movement into gaps in the market created by changes in Japanese competitiveness.²

The Japanese machine tool industry, of course, started to develop more than 20 years before the Korean. In order to make a direct comparison of factors, such as general industrial growth, market orientation, and the effect of government measures, the status of the Japanese industry in the 1950s and 1960s must be assessed. And the differences between the present status of the two national industries must also be examined: firstly, because Korean export industries are having to compete directly on the world market against the fully developed Japanese industries. If Korea is going to maintain its industrialisation, it must ensure that its industries, both export-orientated and import substituting, will be competitive with those of Japan. (Those manufacturing mainly for the domestic market must, in the long run, also become competitive since it is unlikely that they will be afforded protection from imports indefinitely.) And, secondly, such an examination of the later development of the Japanese industry will allow an assessment of possible future development paths for Korea.

7.2.1 Historical Differences

There are three major relevant differences in the character of the industrial backgrounds from which Korea and Japan commenced their modern machine tool production. These concern the available skills and plant at the beginning of their respective enterprises, their development strategies, especially in reference to military considerations, and the sources of the technology drawn upon.

Japan and Korea started their major industrial expansions from very different points. Japan began that expansion already possessing a basic industrial structure, extensive infrastructure, and an accumulation of technological and manufacturing skills acquired from high levels of industrial production before and during the War. South Korea started from a much lower point. It also commenced its development just after the end of a war. The 1950-53 War had destroyed virtually its whole infrastructure, most of its agricultural production, and decimated all its cities except one. However, even before this mass destruction, South Korea had no significant industrial experience: the majority of power production and heavy industry was located in the north and was therefore lost to South Korea after the 1945 division. Furthermore, the industrial capability that had existed before and during World War II was controlled by the Japanese occupying forces, and many skilled Korean workers had been used as forced labour in Japan (over a million of these returned to Korea between 1945 and 1950). Following Japan's surrender, 700,000 Japanese civilians, who had formed the core of managerial and technical expertise, left Korea and returned home. Korea's industrial capacity declined rapidly between 1945 and 1950, and there was mass unemployment among existing workers, returning war workers, and the large numbers of refugees from North Korea.³ The first stage of Korea's development post-1953 was to re-establish an infrastructure and its agricultural base, and early government priorities were focused on agricultural reform and the re-establishment and expansion of an educational system. It was not until these aims had been attended to that any serious form of industrial development was considered. When Korea did start to expand her industries, the only indigenous industry of any size was textiles. In all

other industrial sectors, the country was basically starting from scratch. Thus, while the only import Japan needed for its rapid industrial expansion was technology, Korea required the whole range of plant and skills, from choosing and buying equipment, installing, operating and maintaining it, to the marketing skills needed to sell the final product.

Japan's and Korea's motivations for developing indigenous industries were very different, and these reasons have been embedded in their recent histories. After World War II, Japan's defence spending was severely limited. The development of heavy industries was seen as a way of raising the general wealth of the country and the standard of living of its population. Conversely, the Korean government's main priority since 1953 was and still is national security and the maintenance of forces to protect itself from the perceived threat of invasion from the North. Chapter 5 noted that Korea's entry into the heavy and chemical industries was directly related to its drive to build up its own defence industries, especially following policy statements in the US during the early 1970s that America's contribution towards defence forces in Korea was to be reduced. Japan's industrialisation has therefore been directed towards the expansion of civilian industries, whereas Korea's expansion was orientated towards the support of its own defence production.

Both Japan and Korea were, of course, considerably influenced, in different ways, by the US in their respective post-War years: Japan was occupied by the US directly after World War II, American policy acting to ensure that Japan did not rebuild its military machine, whereas Korea continues to receive substantial military support from the US. A main purpose of the occupation was the stabilisation of the Japanese economy, so that Japan would, as soon as possible, cease to be a drain on American resources. By the early 1950s, Japan was able to take advantage of US needs for military procurement, and became a major workshop and arsenal for the US forces during the Korean War. The Korean War also brought Japan and the US closer together politically, as America realised that Japan could be an important ally in the Pacific (Patrick and Rosovsky, 1976: 55). A major addition to America's military support of Korea was development aid. (Up to the mid-1960s, the US was Korea's most important

source of grant-aid.) It has also been suggested that Korea moved into international trade and exports, rather than developing as a siege economy, as the result of American aid and advice (Nolan, 1986: 92).

Moreover, the world in which each country was developing changed significantly in the 20-year gap between Japan's and Korea's entry into manufacturing industry and world markets. The main source of technology licences was very different for Korea in the 1970s than it had been for Japan in the 1950s. Japan had licensed most of its technology from the US, whereas Korea was able to license most of its required new technology from Japan. Korea also commenced exporting to a radically different world market from the one that Japan first entered. From the 1970s onwards, industrialised countries have been far more aware of the damaging effects of large-scale imports from industrialising countries on their own manufacturing industries, and, in general, the industrialised world began then to defend its own markets by erecting trade barriers which attempt to regulate imports from several NICs as well as from Japan. In addition, in many of the world markets that Korea was and is now entering it faces major competition from established Japanese producers. Japan's competition as it entered world markets came from established and relatively inefficient producers in the industrialised world.

7.2.2 Infrastructural and Governmental Support for Developing Industries

In both Japan and Korea, the role of government in assisting and directing the expansion of the machine tool industries and appropriate infrastructure has been important. In this area, there have been significant similarities in government action. Any industry requires basic infrastructural support. Both Japan and Korea have invested heavily in their infrastructures in order to support development. Korea's task in building up its infrastructure was more difficult than Japan's, as Japan had been left with some of its basic infrastructure intact after the Pacific War. To help certain industrial sectors in their development, the Korean government established special industrial sites, on which all the required infrastructure was installed by government.

The level of education of a country's workforce, of course, affects the type of work that can be successfully undertaken. The establishment and continued funding of an educational system is an important role of government and both the Japanese and Korean governments attended to this at an early stage. In 1947, Japan made nine years of schooling compulsory and introduced the basic organisational structure of the American school system. Voluntary further education was expanded and an increasing number of students took advantage of these opportunities. The Japanese workforce is now one of the most highly educated in the world. Korea has similarly emphasised education in relation to industry. By the mid-1970s, the proportion of 17-year olds in formal education in Korea - although still less than in Japan - exceeded the rate in the UK (Golladay and King, 1979: 154).

Specific policies were also implemented by the government in each country to encourage economic growth and industrialisation. The measures introduced by the Korean government in the 1960s were mainly aimed at the expansion of export (mostly light) industries and were different from the Japanese government's early encouragement of domestically orientated heavy industries. However, the policies of both governments (Japan's in the 1950s and Korea's in the 1970s) promoting the development of heavy

industries bear striking similarities, as do the specific measures introduced to promote the machine tool industries. In both countries, the expansion and entry into the heavy and chemical industries occurred as a direct result of government policy. Large modern steel mills, shipbuilding yards, oil refineries, chemical works, and metal working factories were all constructed during this early phase of technology- and skill-intensive industrial development. Entry into these industries by Korea coincided with Japan's contraction of its polluting heavy and chemical industries.

Government promotion of machine tool industries in both countries included the use of subsidised loans encouraging producers to invest in capital equipment. But only in Korea were firms encouraged to establish new plants on an industrial site purpose-designed and built for machinery production, and only in Korea were exporters favoured in the allocation of subsidised loans. Low-interest financing was also made available to domestic user industries for the purchase of new domestically manufactured machinery in each country.⁴ Such funding was of particular importance to the machine tool industry, since it considerably increased domestic demand, as well as allowing the industry to renew its own production equipment.

Both governments also protected the domestic market, without penalising machinery users, by only barring imports of machines which could be domestically produced to satisfactory standards. In neither country was protection given for very sophisticated machines nor for domestically manufactured machines which were sub-standard. In Japan, high-quality machine tools were allowed to be imported tariff-free from 1952, the government only restricting the import of standard machine tools which would compete with domestically made goods. Tariffs continued to be used as a mechanism to protect the domestic market even after some areas of Japanese trade had been liberalised in the 1960s and 1970s. In the 1970s, tariffs of between 10% and 20% were applied to imported machine tools, the size of tariff depending on whether or not the imports competed with domestic production. Protection of the domestic market ceased in 1983, when all tariffs on imported machine

tools were finally lifted (Chokki, 1986: 137). Thus, Japanese machine tool producers enjoyed varying degrees of protection on their domestic market for over 30 years.

In contrast, in Korea the final responsibility for regulating the importation of high-value machinery was delegated to a parastatal organisation, KOSAMI, to which all of the major machinery manufacturers belonged. Because of mounting global pressure against trade restrictions, especially from the US, and an increasing attitude of laissez-faire in the mid-1980s, the Korean government has reduced the protection of its domestic market. The effects of this early liberalisation of machinery imports on the Korean industry are not yet known.⁵

The Japanese government at various times tried to limit competition on the domestic machine tool market by restricting the number of producers and encouraging firms to merge. Through the 1956 Temporary Measures for the Development of the Machinery Industry Law, a rationalisation plan for the machine tool industry was drawn up with the aid of the Japanese Machine Tool Builders Association (JMTBA). This plan called, firstly, for production of machine tools to be concentrated so that producers would benefit from economies of specialisation, secondly, for an increase in the standardisation of machine tool parts, and, thirdly, for the establishment of collaborative research. In the implementation of this plan, firms were encouraged to concentrate on their existing products and not to enter new product areas. A later version of the plan in 1961 (using a five-year extension to the 1956 law) also aimed to concentrate production and recommended "appropriate" batch sizes for the manufacture of various types of machines (Fransman, 1986a: 193). In the mid 1960s, MITI considered that the industry was still not concentrated enough and, as demand declined, that producers were becoming too competitive. Firms were encouraged to cooperate in groups, and firms manufacturing machines which were not of an adequate standard, or in which machine tools only formed a small proportion of total output, were recommended to discontinue production (Chokki, 1986: 142). While these measures had some success in the short term, in the longer term most producers re-entered and fierce competition on the domestic market has

remained.⁶ Similarly, Korea's government has limited competition by declaring which firms can produce certain items. In particular, it limited competition in the production of vehicles. The Korean government has also forced firms to merge in an attempt to reduce the effects of some of the mistakes of over-expansion in the heavy and chemical industries. As shown in Appendix 2, this type of measure has been used recently to merge a failing machine tool producing firm (Firm E in the case study) with a more successful one (D).

In both countries, government-funded research institutes were established to support the technical development of many industries, including the machinery sector. In Japan, the major collaborative projects were government- or Ministry of International Trade and Industry (MITI)-instigated and involved several firms, while in Korea the projects involved only individual firms and the research institute - often at the firm's request. Large collaborative projects in Japan have all included a base of research work into new technologies and have been undertaken by teams from several firms.⁷ The Korean projects, at KIST, were all undertaken in the very early stages of CNC development and were directly developmental and problem-solving in character with no significant research content. Although the Korean government did reorganise its research institutes to form laboratories which were more industrially orientated, the institute for the machinery industries (KIMM) does not seem to have carried out any significant development work with the CNC machine tool producers.

The direct effect of government intervention on industrial development is a fundamental issue in development economics. A notable feature of government's action in both countries has been their control of foreign exchange, enabling them to direct credit to the specific industries they wanted to promote. The overall role of the government, and especially MITI, in Japanese development has been greatly debated. Patrick and Rosovsky suggest that the principal motor behind Japan's growth has been the private sector, but they conclude that, by protecting the domestic market, accelerating development of key industrial sectors, and providing infrastructure, government has made growth easier (1976:

20, 47-48). However, it is clear that the Japanese government did more than provide an environment. For example, Ozawa argues that

[G]overnment control over technology imports was tantamount to the control over the direction of industrialisation and structural change. In fact, MITI initially did use technology imports as a means of orchestrating the reconstruction and expansion of Japanese industry (1985: 229).

While MITI did have considerable influence over which companies were given access to specific new technologies, the number of competing firms and the size of newly constructed plants, its power over Japanese industries should not be overestimated. Vehicle producers refused to follow MITI's instructions to reduce the number of competing firms, and, in the case of the steel industry, MITI was unable to stop two firms obtaining different technologies from the one it was promoting at the time.⁸

In both Japan and Korea, governments did actively influence and promote the early and rapid development of their machine tool industries.⁹ The most important and effective measures introduced by these governments were the initial provision of subsidised funding to specific firms and the continuing selective protection of the domestic market. These measures helped firms establish themselves and expand their productive abilities, while ensuring them a market for their products. Additional government measures were also used to enlarge domestic markets and to encourage the purchase of domestically produced machinery. (Chapter 4 showed that this measure was also effectively used by the Italian government to support its machine tool industry.)

However, in both countries a machinery industry would almost certainly have eventually developed without government intervention, though probably at a later time. And, if this were so, then, during that period of delay, each country's machine tool users, especially the vehicle industries, would not have enjoyed the technical support of a developed indigenous machinery industry. The absence of such support may have been detrimental to their purchase, modification and expansion of

manufacturing plant. The early competitiveness of machine-using industries may therefore have been promoted by government policies encouraging the existence of an indigenous capability in machine tool production.

Unfortunately, the only material dealing with the direct role of these governments in the acquisition of imported technology and in the negotiation of terms pertains to other industries, mostly very large technology importation projects such as steel production, chemicals, and, in the case of Korea, nuclear power. In these sectors, the governments of both countries were highly interventionist in their regulation of the conditions of technology agreements, working to ensure that technology was effectively transferred and assimilated.¹⁰ In the machine tool industry, there does not seem to have been any explicit government intervention in individual agreements, either in Japan or Korea. The agreements were, of course, regulated by government-imposed general conditions pertaining to all technology imports, such as set maximum levels for royalty payments and duration of agreements.

7.2.3 The Domestic Market and Links between Users and Producers

Perhaps the single most important consideration in the development of Japan's and Korea's machine tool industries has been the size and nature of their respective domestic markets. The effects of these markets on the career of the two industries are three-fold. Firstly, the size of the domestic market influences which products can be made for that market at an economic scale. Domestic demand below a certain level means either that the product is not made indigenously, or that a part of domestic production must be exported to make the enterprise economically viable. Secondly, the structure of domestic manufacturing influences which types of machines are required on that market, and, hence, the types manufactured by the domestic industry and the capabilities which are absorbed into the industry. Thirdly, the existence of a substantial domestic market means that opportunities exist for the machine tool industry to develop in concert with the needs of the users of its

products. A close relationship between machine tool producers and local consumers enables the former to understand and quickly to respond to the changing requirements of its customers. In the absence of such domestic links, machine tool producers may find themselves obliged to follow technological leads of other national industries, and, moreover, at the cost of some delay. Such industry-user links have, for example, been noted in the case of the Swiss machine tool industry and its close association with the high-precision watchmaking industry. In Japan, the requirements of the vehicle industry have been decisive, and in Korea a similar situation is evolving. Needless to say, such domestic capabilities are of enormous benefit to machine tool users as well as producers, and the long-term success of users works to the benefit of machinery producers.

In both countries, the domestic market absorbed most of the early increase in production. In order to supply increasing domestic consumption of machine tools, between 1955 and 1961 Japan's production rose 22 times by value while exports only increased three-fold (see Table 7.1). Production and consumption both slumped in the mid-1960s, but rose again rapidly in the late 1960s and early 1970s. During this period MITI set an export target of 20% to be reached by 1970. However, because the domestic market was expanding, most machine tool builders concentrated on supplying domestic requirements before exporting, and this export target was not reached until the mid-1970s (Vogel, 1985: 74-76). Japan has maintained a very high level of machine tool consumption, and, despite the rapid growth of its machine tool exports since 1975, the domestic market has continued to be its major customer; in 1985, less than 40% of Japan's machine tool production was exported (see Tables 4.1 and 4.2). Korea's machine tool output increased nearly nine times between 1977 and 1987, and in the latter year less than 10% of this production was exported. Although Korea has a large domestic market compared to other industrialising countries (since 1985 it has been the largest NIC consumer of machine tools), compared to Japan its domestic consumption is still fairly small. In 1985, Korea's consumption of machine tools was less than 10% that of Japan. However, with the rapid growth of the

Table 7.1 Japan's Machine Tool Production and Trade 1945-81

(Unit: Weight in tons, value in millions of yen)

Year	Production			Exports (B)	Imports (C)	Domestic demand (A)-(B)+(C)	Export ratio	Import depend ence
	Units	Weight	Value (A)					
1945	7,316	11,810	130	0.1	0.04	129.0	0.1	0
46	4,791	4,289	106	0	...	106.0	0	...
47	5,544	3,228	150	0.9	...	149.1	0.6	...
48	8,051	4,690	500	1	...	499.0	5.2	...
49	6,680	4,473	861	51	42	862.0	37.9	4.9
50	4,039	2,948	566	214	133	452.0	37.8	29.4
51	9,139	4,714	1,066	286	134	930.0	26.8	14.4
52	11,587	5,946	1,707	352	848	2,203.0	26.8	38.5
53	18,722	7,747	3,738	411	2,254	5,319.0	11.0	42.4
54	18,124	10,541	5,385	549	5,229	10,066.0	10.2	51.9
55	18,147	6,591	3,680	715	4,042	7,007.0	19.4	57.7
56	28,068	11,626	7,174	527	2,523	9,170.0	7.3	27.5
57	34,824	21,406	15,549	724	12,201	27,026.0	4.7	45.1
58	32,652	26,290	21,113	479	13,777	34,411.0	2.3	40.0
59	47,830	31,443	24,318	497	10,449	34,270.0	2.0	32.3
60	80,143	59,619	45,169	1,624	19,701	63,246.0	3.6	31.1
61	114,959	110,102	81,882	2,434	38,899	118,347.0	3.0	32.9
62	104,701	127,105	100,892	2,587	47,581	145,886.0	2.6	32.6
63	120,541	126,558	95,132	4,295	22,796	113,633.0	4.5	20.1
64	131,053	121,538	90,906	6,509	21,319	105,716.0	7.2	20.2
65	90,356	89,242	70,349	8,943	13,963	75,369.0	12.7	18.5
66	107,969	98,373	76,453	14,611	7,586	69,528.0	19.1	10.9
67	153,949	149,685	126,041	16,642	12,839	121,238.0	14.1	10.5
68	184,260	194,984	175,986	18,584	34,176	191,578.0	10.6	17.8
69	231,419	255,384	239,988	21,747	34,485	252,651.0	9.1	13.6
70	256,694	315,821	312,349	24,088	44,162	332,423.0	7.7	13.3
71	183,649	254,870	264,405	28,044	39,762	276,123.0	10.6	14.4
72	164,553	195,910	205,180	27,408	22,366	200,138.0	13.4	11.2
73	212,586	255,239	305,223	35,237	21,332	291,319.0	11.5	7.3
74	168,952	237,981	358,610	57,664	37,211	338,157.0	16.1	11.0
75	88,108	139,207	230,739	61,611	21,575	190,703.0	26.7	11.3
76	118,994	132,617	228,604	76,073	13,867	166,398.0	33.3	8.3
77	131,405	159,511	312,844	115,493	15,720	213,071.0	36.9	7.4
78	136,617	176,663	365,525	162,138	19,638	223,025.0	44.4	8.8
79	164,207	220,892	484,132	206,643	26,214	303,703.0	42.7	8.6
80	178,890	275,450	682,102	269,577	38,221	450,746.0	39.5	8.5
81	165,631	317,133	851,561	310,763	38,623	579,421.0	36.5	6.7

Source: Metalworking, Nov. 1982: 182

Korean market, by 1987 Korea's consumption reached 22% that of Japan (American Machinist, Feb. 1988: 62).

Although there were no major differences between the relevant policies implemented by the Japanese and Korean governments, their motivations for promoting the machinery industry, and in particular the machine tool industry, were very different. In the case of Japan, measures were introduced to encourage the development of the industry so that it could support other sectors of domestic manufacturing. In Korea, the major motivation for the initial promotion of the machine tool industry was to support the development of an indigenous defence capacity. However, despite this early military concern, defence procurement now only accounts for a small proportion of Korean machine tool output in comparison to purchases by the vehicle and other civilian industries. While there is some production specific to military requirements, a large proportion of defence work is undertaken by private industry, and this has, where possible, been integrated with the manufacture of similar civilian goods.

In Japan, competition on the domestic market was an important factor in the rapid technological development of many industries. Competition between Korean producers appears to be much less intense. There are far fewer Korean machine tool producers in each product sector, which means that each firm has correspondingly fewer direct competitors on the domestic market. Korean firms confirmed in interview that their users had few alternative domestic suppliers, and, consequently, that there was little direct competition on this market. For exports, however, the situation is different. Foreign buyers, of course, have a far greater choice, and have little or no difficulties finding alternative suppliers on the world market. Since the export of Korean machine tools has been promoted by government, for Korean firms international competition may act as a substitute for intense domestic competition in ensuring continuing attention to cost, quality, and product development. The reduction of protection on the domestic market should have a similar effect, domestic producers being forced to compete against imports.

In Japan and Korea, a large proportion of the growing demand for machine tools came from the developing mechanical engineering sector, and, in particular, the vehicle industry. This industry now forms the largest single market for the machine tool producers of both countries.¹¹ The vehicle industry requires specialist equipment, as well as more standard machines, and in both countries there are considerable technical links between machine tool and vehicle producers. The large Japanese components industry, which supplies the vehicle industry, is also a very large machine tool consumer. Its requirements are less specialised than those of the vehicle industry, as it uses mostly fairly standard general purpose machines. In Japan, it was this large market that accounted for a significant proportion of the early growth of CNC machine tool demand. Korea's vehicle components industry is less well developed; however, it is rapidly expanding and its demand for machine tools is growing accordingly.

In both countries, the most consequential inter-firm linkages have been between machine tool producers and the local vehicle industries. Indeed, it is a characteristic feature of both countries that vehicle producers have established their own machine tool capabilities. Most of the major vehicle producers in Japan have their own machine tool divisions or subsidiaries. Two of the large Korean vehicle producers have followed this example and the third is increasing its links with a machine tool firm in a different division of the *chaebol*. In the main, machine tool firms directly linked to vehicle producers manufacture machinery that is specific to the latter's requirements, and, consequently, a high proportion of their production is in special purpose machinery.

Even though many vehicle producers in both countries have their own machine tool building capabilities, they still have very close links with other domestic machine tool firms. Chapter 6 noted that the single large independent firm in Korea has supplied lines of machinery to one of the vehicle producers, and that one of the *chaebol* firms (which has some links with its own sister vehicle producer) has supplied an FMS to a vehicle producer in another *chaebol*. Similarly, in Japan there are very close links between all machine tool producers and the vehicle industry.

Moreover, the requirements of the Japanese vehicle industry are an important influence on product strategy and development in the machine tool industry, even in the independent producers. These extremely close inter-firm links between machine tool and vehicle producers in Japan were an important feature of the technical development of NC and CNC machines. The vehicle industry, and its complex network of sub-contractors, required small, low-cost machinery, and this was the type of machine developed by the industry. Indeed, it was these machines which led Japan's exports in the early 1980s (see Watanabe, 1983: 20-26 for a detailed analysis of these links).

Of course, while the vehicle industry is of crucial importance for machine tool production in both countries, it is by no means the only sector which can promote new product development. For example, in Korea there is now a large industry manufacturing EDM machines for mould producers, and CNC copy milling machines have also been developed specifically for these users. The production of laser cutting and marking machines by one firm started after a large domestic market for these machines had already formed. At present in Japan the requirement of the microelectronics industry for high-precision machinery has meant that many Japanese machine tool producers are now developing new machines specifically for this market. The internal market of the machine tool industry itself is an important force in product development. In the acquisition of FMS capabilities in Japan, machine tool producers were able to use their own internal market to build and de-bug workable systems before they started to install them in other industries. Similarly, in two Korean firms the internal market was large enough to support the development of FMS, either within their own manufacturing plants or within the relevant *chaebol*.

Japan's production in many industrial sectors expanded in order to meet increasing domestic demand, and a range of industries developed products to suit its domestic market. The experience gained from producing for the domestic market, and the establishment of long production runs, enabled many Japanese industries, including the machine tool industry, to enter world markets with a proven product and at a

competitive price.¹² The demands of Japan's domestic market were, and still are, key elements in its product developments. As Korea's domestic market is much smaller than Japan's, its scope for continuing to expand production to meet increasing domestic demand is more limited compared to the import substitution opportunities open to Japan's industry. This has two consequences for the development of Korea's machine tool industry. Firstly, it has to be more specialised than the Japanese industry, concentrating on producing a narrower range of machines. Secondly, Korea's producers have not been able to benefit from such large economies of scale in production for the domestic market, and, therefore, must export at an earlier stage in development in order to achieve such economies. However, the domestic market is large enough for Korea to use it to develop new products and refine its production techniques before commencing export. The continuing importation of a large percentage of domestic machine tool requirements (in 1987, imports still accounted for nearly 50% of total machine tool consumption) indicates that there is still some room for Korean producers to further expand their supplies to the domestic market.

In summary, the most significant features of the development of the machine tool industry in Japan have been the size and structure of the domestic market, and the close cooperative links between users and producers. These links have enabled Japanese manufacturers to produce high-quality, low-cost machine tools, and, notably in the case of manufacturing for the vehicle industry, basic and adaptable products which are now world market leaders. Although the Korean domestic market is only a fraction the size of Japan's, several of the characteristics of that market show interesting similarities with the Japanese experience. Most notably, close inter-industry links between machine tool and vehicle producers have been established and the technological benefits of these links are now being made manifest in both industries. It is plausible that these characteristics of the Korean domestic market will enable its machine tool industry to enhance its capabilities and increase its competitiveness on the world market.

7.2.4 Technology Acquisition

It is important to stress that the Japanese machine tool industry took a very long time to develop from the basic technological level of the immediate post-War years to technological parity with producers in other industrialised countries. (A report by the JMTBA suggests that the industry took at least 25 years to achieve such parity (Metalworking, Nov. 1982: 158).) During this time, the domestic market was protected and manufacturers were given numerous government incentives to encourage their commercial and technical development. In fact, the domestic market was sheltered for over 30 years, firstly through foreign exchange control and later with tariffs. Imported technology formed an important input for technical development, but was accompanied by sustained indigenous technological efforts, especially in the early development of NC.¹³ Until the industry reached international standards in the mid-1970s, the majority of growth in output was absorbed by the domestic market. Only after the industry had attained a technical level similar to other industrialised countries did exports become an important feature of its sales. Korea's machine tool industry only started to expand in the mid-1970s, and it is still in the process of acquiring new technologies and learning new capabilities. Indeed, in many product areas, including CNC production, it is even now at an infant industry stage.

Korea and Japan have both based their rapid industrialisation programmes on the importation of foreign technology. In the case of Japan, the major source of new technology was the US, and in the case of Korea, the major source of technology was Japan. In both countries technology was mainly imported through formal technology agreements, but imported turnkey plant and machinery were also important sources of new technology. In Japan, direct foreign investment was only permitted when this was the only way in which technology could be acquired. In Korea, direct foreign investment has been far more widespread, and in the free trade zones it was actively encouraged. Even so, only a small proportion (less than 10%) of investment in manufacturing in Korea in the 1960s and 1970s was in the form of direct foreign investment, and in the machine

tool industry there have been few instances of direct foreign investment.¹⁴

Economists have used the reversal of the direction of technology trade as an indicator of technological development. Although the payments for foreign technology by Japan in the early 1980s were larger than its receipts, Lynn (1985) documents that many of these payments were for agreements which had been made several years earlier. By considering only the current trade from new technology agreements for each year, Lynn shows that Japan has had a surplus in such trade since the early 1970s. Initially, most of Japan's technology exports went to developing and industrialising countries; however, American and European firms are increasingly utilising Japanese technology and product designs to try to regain some of their lost market share. The change in the direction of technology exports by the machine tool industry itself adequately demonstrates this point: early technology exports from Japanese machine tool firms (in the early and mid-1970s) went to manufacturers in countries such as Korea and Taiwan. By the mid-1980s, Japan had become the main source of technology for both the US and Britain, as well as remaining the most important supplier to the NICs.

For Korea, such a reversal of technology trade is yet to be attained and technology imports still form a major component of new industrial developments.¹⁵ However, Korea has commenced exporting technology; Enos and Park (1988) show that in the iron and steel industry, technology and know-how have been exported to Taiwan and Indonesia, and in the synthetic fibre industry Korean engineers have participated in plant start-ups in Thailand, India, and Taiwan. Westphal et al. (1984) also describe exports of technology by Korea in the form of turnkey plant construction, direct investments in manufacturing facilities, the licensing and sale of technical services, and engineering and management consultancy. Any export of technology indicates that a country has "accumulated skills and knowledge [in that industrial sector] within its own borders, based on its own experience and effort" (Lall, 1982: 9). Korea is still a long way behind Japan in the process of industrialisation and technological development, but is beginning to supply technology to less industrialised

countries in the same way that Japan first exported technology. Importantly, Korea has also become a direct foreign investor. However, it is unclear in some of these cases, e.g., Hyundai's car assembly plant in Canada, and other plants in already industrialised countries, whether Korea is exporting technology or not. While in these cases the recipient countries are not (or should not be) gaining new technologies, such investments do show that Korea has a considerable level of manufacturing skill and technological capabilities. Although the technology embodied in the machine tools manufactured in Korea is exported, and may, as such, be thought of as a technology export, the machine tool industry is not yet exporting any of its technology in the form of design, consultation services, or licensing agreements. The direct foreign investment in Germany by one of Korea's machine tool producers (Firm C) is definitely not a case of technology export. Indeed, it is the reverse, as the firm bought already established companies and has used them as a source of technology for its own development rather than supplying the purchased firms with Korean technology.

Although Korea is no longer totally dependent on foreign technology for its development, compared to Japan it has not assimilated imported technology as efficiently. Korea has used repeat licences in many technologies, including machine tools, and in other industrial sectors has allowed far more direct foreign investment as a potential, although widely debated, technology source. A major factor in the difference in the rates of technology assimilation must be the different industrial structures in Japan and Korea at the outset of their industrial development. As already noted, Japan had the advantage of an established industrial base on which to build and on which technological capabilities could be rapidly assimilated and expanded, whereas South Korea had no such advantages when it began developing its industries. Consequently, while Japan only needed new technology, Korea has had to acquire a far greater range of technological and managerial capabilities.

The Japanese machine tool industry, like the Korean industry, used licences to build machines of new designs and to acquire technology. Although Metalworking details the agreements entered by machine tool

producers in the 1950s and 1960s, unfortunately the total content of these licensing agreements is not available (see Metalworking, Nov. 1982: 156). However, as the industry already had substantial capabilities, it is unlikely that the agreements contained much more than the designs of the new machines. The Japanese producers did learn about the construction of foreign machines through collaboration with the JMTBA, which imported new machines and dissected them. (Vogel (1985: 71) documents that in the mid-1950s a MITI grant of ¥25 million was given to a laboratory, presumably JMTBA's, to support the purchase and study of foreign machines, and in 1967 a further grant of ¥485 million was given to support similar work on NC machines.) Korea and Japan have both supplemented their use of licensing agreements with a wide range of other learning mechanisms to build up their technological capabilities. The most important of these mechanisms in both countries have been the training of personnel in foreign firms and universities, and the employment of foreign consultants to advise on indigenous production facilities, assist in quality control, and train personnel.

Significantly, in both countries technology imports were accompanied by indigenous technological efforts. Indeed, the development of NC machines in Japan depended on such efforts and not on formal imports of the new technology. Early NC machines were developed in Japan in the mid-1950s by the Fujitsu research group, which later became Fanuc, and various machine tool builders. This work used technical information from the original MIT project. The major expansion of NC development and production occurred in the late 1960s and early 1970s when the market for NC machines was rapidly expanding and the technology was proven to a greater extent. Again, these developments were mainly indigenous and only a few licences were used. There are two plausible reasons why, at different stages in development, licences were not extensively used. Firstly, in the late 1950s and early 1960s, NC technology was still in an embryonic stage. For several reasons, very new technology and product developments are rarely transferred through formal technology agreements. New producers are unwilling to license recently developed technology on which they have not received a significant return on development costs. Furthermore, Chapter 2 suggested that new technology which has not been

widely tested and diffused is difficult and costly to transfer for both the licensee and licensor. Secondly, in the early 1970s, when many more Japanese producers commenced production, there were few machines being manufactured abroad which were suitable for the Japanese market. Japan's developments at this time were concentrated on small, low-cost NC machines, while the majority of the machines being manufactured in Europe and, especially, in the US were very large, high-precision, sophisticated machines developed for defence production. Japanese producers were therefore developing an entirely different product from those manufactured abroad and would have found great difficulties in finding the right technology suppliers in other national industries.

The collection and dissemination of information on market changes and technology developments (learning by searching), especially through trade missions and exhibiting at international trade fairs, has also been an important input for firms in Japan and Korea. In this type of learning, the two national industries have both been aided by their manufacturers' associations. And these associations have also worked with their respective governments in the formulation of development plans and in determining the level of protection of the domestic market. However, in general, KOSAMI and KOMMA appear to be much weaker organisations than JMTBA and have not been so influential on the development of their membership.

As already noted, firms also enhanced their product designs and technological capabilities through collaborative projects with government-funded research institutes. However, these projects have been fundamentally different in each country; in Japan, they were large-scale projects involving several machine tool producers, while the Korean projects involved only individual firms. The scope of the projects was also dissimilar, those in Japan containing some new research work, while the Korean enterprises focused purely on product development. Consequently, Japanese and Korean firms have benefitted to different extents from these projects. Japanese producers thought that the national MITI projects did have important benefits for them, but did not regard them as a major element in their technical development. In Korea,

firms considered that such projects were important for their initial entry into CNC production, but few firms had subsequently taken advantage of the development facilities organised for them. The *chaebol* firms had developed greater skill levels within the conglomerate structure and so did not need the support of the research institutes, while projects with small firms were difficult to set up.

The Korean and Japanese machine tool industries have differed in the nature and quality of the support received from controls producers. In the Japanese case, close technical links between machine tool and controls producers have facilitated concerted product development. With the entry by machine tool producers into FMS, an understanding of electronics and the ability to write software has become increasingly important. And a machine tool industry that lacks this close technical support suffers corresponding competitive disadvantages. In the development of NC machines, Japanese firms benefitted from the support of the progressive electronics producer, Fanuc. The producers have also been able to rely on Fanuc to manufacture reliable equipment and to continue to develop new, and technically more advanced, products. Korean machine tool producers have to some extent benefitted from the technical support offered by Fanuc, but they cannot collaborate with Fanuc in new product developments. Furthermore, the simple economics of the relationship between Fanuc and machine tool producers is a vital issue: Japanese firms get their controls at a significantly lower price. Although Korea does have an electronics industry, it is much younger than the machinery industries and has not been able to offer similar support. However, the electronics sector in Korea is growing rapidly, and in the future it should be able to give more support to the machinery industries. Faster microprocessors and easier production of semi-customised chips should in future help Korean producers in this field.

As the machine tool industries of Korea and Japan have responded to the particular machinery needs of their users, and in particular to those of the vehicle industry, they have acquired a very broad range of design and production skills.¹⁶ The Japanese machine tool industry has developed to the point where there are few machines it now needs to

import, and it has an excellent pool of skills required to design special purpose machinery for its user industries. Importantly, the Korean machine tool industry is developing in a similar fashion. Nearly all the sample firms in Korea undertook some form of custom design and several were also able to design special purpose machine tools. The Japanese machine tool industry has, of course, been quite capable of supplying machinery adapted for new product developments for several years, and this is an important consideration in many of the industries in which Japan is now a technological, as well as a market, leader. Although Korea does not yet have this ability, the development of skills in the design of special purpose machinery is an important step towards acquiring such a capability.

7.2.5 Conglomerates

A characteristic feature of the industrial structure of both Japan and Korea is the existence of very large industrial conglomerates, known respectively as *keiretsu* and *chaebol*. Although the *keiretsu* and *chaebol* are similar in the scope of their manufacturing activities, there are significant differences in their structures and organisation. The *keiretsu* are groups of companies clustered round one or more core banks and trading companies. The firms in the group coordinate their industrial policies, and their presidents meet regularly. The ownership of each company is often very complex. As individual holdings in each firm by other companies, or banks, is limited, cross-ownership within each group is very common, and frequently a large proportion of stock in each firm is held by several other companies within the same *keiretsu*. The core banks are the major source of credit to each company, and the firms are also often linked through purchasing arrangements. This conglomerate structure only formed after World War II, following the limits placed on company ownership introduced during the US occupation (Fransman, 1988: 117). The *keiretsu* formed out of 19th-century conglomerates known as *zaibatsu*. These were groups of companies which all belonged to a holding company, and were originally under the control of a single family. The holding company, which controlled the production of each component firm,

became more important as the *zaibatsu* grew and a larger number of managers from outside the founding, or controlling, family were employed. The structure of the Korean *chaebol* is quite similar to that of the pre-War *zaibatsu*, and in several cases *chaebol* are still controlled by a single family (Jones and Sakong, 1980: 259). Unlike the *keiretsu*, the *chaebol* do not include banks in their structure, as all Korean banks were, up to the early 1980s, under government control. However, during the main period of *chaebol* growth in the 1970s, their leaders were in very close contact with the Korean government and were the major recipients of preferential loans arranged during the expansion of heavy industry.

Although the structures of the *chaebol* and *keiretsu* are different, the benefits of membership are similar. The range of products manufactured within each conglomerate is very broad, and, in general, the products are complementary. Firms do not compete directly with others in the group. The manufacture of complementary products enables conglomerate members to take advantage of economies of scope. These economies accrue from the ability to centralise certain functions. In particular, trading for several companies is often undertaken by a single firm. This reduces costs in export markets as only the single trading company needs to establish an overseas presence. Also, companies in similar manufacturing areas often have combined research and development facilities, whose results are made available to all members. Trading within the groups, such as exists between linked vehicle and machine tool producers, is also common.

The sharing of technical and business information is a very important benefit of group membership. Internal trading links automatically ensure that there is information transfer and feedback between firms and extremely close technical bonds can be formed. As the range of industries in each group is very wide, individual firms have access to a equally broad range of technical information, collaboration and support. The trading companies also play a key role in the group's information exchange. These companies have an international network of sales offices which gather market and product development information and transfer it to other companies within the group. Although many of the

links between firms in the *keiretsu* are now informal, the obvious benefits received through such links ensure that they are maintained.

The group structure enables direct information flow between machine tool user and producer, and allows collaboration in plant development and problem solving. Indeed, in some cases machine tool manufacture takes place on the same industrial site as vehicle production. Such close interaction would not be possible for an independent producer. The intimate technical relationship between vehicle and machine tool producers also enables new machinery to be developed in tandem with the new vehicles for which it is intended. Thus, the method of production used in the manufacture of the new model is considered while it is still on the drawing-board and potential manufacturing difficulties may be eliminated at a very early stage.

In both Japan and Korea, conglomerates have been an important aspect of industrial and technological development. However, while in Korea the major proportion of growth in the machine tool industry took place in *chaebol* firms, in Japan, growth in independent firms has been as important. In fact, many of the leading Japanese producers remain as independent companies. One possible explanation for this difference is that, at the outset of the development and growth phase in the late 1950s, several independent Japanese machine tool firms were very much larger than the independent Korean firms at a similar stage of development. Watanabe (1983) found that of six early NC producers five had more than 1000 employees. Of these, at least two were independent firms (as was the sixth firm which had less than 1000 employees). In Korea, only one independent firm in the mid-1970s had more than 300 employees (Bendix et al., 1977). Thus, while in Japan some of the independent firms had the resources and manpower to invest in expansion and new product development, there was only one such firm in Korea. As the majority of new funding in Korea in the 1970s was directed towards the *chaebol*, these firms accordingly accounted for a large share of growth in this sector.

Although *keiretsu* membership was not a particularly important feature of the expanding Japanese machine tool industry, such membership was important for controls producers, and, especially, for Fanuc. (Other major *keiretsu* controls producers include Yaskawa, Mitsubishi, Hitachi, and Toshiba.) Fanuc was financially subsidised by Fujitsu for the first nine years of its operations. It was also given technical support by other members of the group; for example, in the early 1970s, Fanuc collaborated with Fujitsu in the design and development of LSI circuits to be used in control units (Vogel, 1985: 82-83). As noted in Chapter 4, Fanuc became an independent firm in 1972; however, Fujitsu retained a large share-holding in Fanuc, and there are still close technical and market links between them. In Korea, some machine tool producers are members of *chaebol* which also have microelectronics manufacturing interests. The successful development of control units by either the machine tool or microelectronics division in these *chaebol* could be considerably aided by the links between the two divisions.

7.2.6 Exports

The world market for CNC machine tools has been dominated by Japan since the early 1980s. In seeking to establish itself in that market, the fundamental fact Korea faces is Japanese dominance. This presents both advantages and disadvantages for Korean producers. What lessons can Korea learn from Japan's successful export experience? How has Japanese trading influenced Korea's ability to penetrate export markets? What new techniques is Japan now developing to further enhance its efficiency and competitiveness, and how may such techniques affect Korean exports? Is it likely that Korea can come to compete with Japan, and, if so, on what terms?

Korea's future depends on its ability to continue improving its industrial capabilities and, eventually, to develop new products and technologies. Korea's products have also to remain competitive on the world market. However, as its domestic market is smaller than Japan's, opportunities for economic import substitution are less, and exports must

be used to finance the import of products which are not substituted. Additionally, Korea needs to earn substantial sums of foreign exchange in order to service and repay its huge foreign debts, an obligation it has to date been well able to fulfil.

Japan initially exported machine tools to other Asian countries before it commenced large-scale exports to the US and Europe. Korea's early machine tool exports in the late 1970s also went to other Asian countries, but the proportion of exports to the US and Europe has increased in the early 1980s and reached over 80% in 1984. Korea has, therefore, followed Japan's example of initially exporting to countries which require the very basic machines it was able to produce in the early stages of product development and, only then, when production experience and capabilities were enhanced, entering the markets of industrialised countries.

The export experience of the Japanese CNC machine tool industry is very similar to that of many of its other high-technology industries, such as vehicles, and consumer and industrial electronics products. Japan achieved very rapid export growth and high levels of penetration in the markets of industrialised countries by supplying competitively priced, high-quality goods against which these countries' producers could not effectively compete. Japan, therefore, entered markets in which there was little potential competition for its superior, low-cost products and, consequently, a very high potential for market growth. This type of penetration is well demonstrated by Japan's domination of the American CNC market to which it supplied over 40%, in terms of value (and nearly 60% in unit terms), of the CNC machines sold in 1985 (Metalworking, May, 1987: 21).

It is to this more competitive part of the world market that the Korean machine tool industry is now exporting in very small quantities, and Japanese producers are considered to be its major competitors. While in some labour-intensive industrial sectors Korea was able to fill gaps in the world market created when Japanese industry moved out, in more high-technology industries, including CNC machine tools, Japanese

producers show no signs of relenting in their quest for larger market shares. Although Korean producers are concentrated at the "bottom end" (the smaller, lower-powered, and less sophisticated part) of the market, Japanese manufacturers are maintaining their share in all product sectors. Consequently, if the Korean machine tool industry is going to increase its levels of exports, it must ultimately be able to compete with Japan.

Important features of Japan's ability to maintain its competitiveness in the world market include its establishment of highly efficient manufacturing industries which benefit from economies of scale in production, and the application of innovative manufacturing methods, which give them high rates of productivity and better quality goods. While machine tool production has traditionally been undertaken in small batches, Japanese producers, by extending their production runs, have been able to utilise mass-production techniques. As the main developers and suppliers of FMSs, many machine tool producers have installed such systems in their own factories. Japanese producers have, therefore, automated certain parts of their production. Typically, these systems are run on a three-shift basis. Methods collectively referred to as "Japanese manufacturing techniques" have also enabled quality improvements and further reductions in manufacturing costs. These methods of production and production management include Just-in-Time (JIT), Total Quality Control (TQC) and Quality Control Circles (QCC). Abernathy et al.'s (1981) study of Japanese and American car manufacturing shows that an average of 112.5 man-hours were required to assemble a small Ford, whereas, using Japanese manufacturing techniques, a similarly sized Mazda used just 47 man-hours of Japanese labour. When expressed in terms of late 1970s labour-costs, the contrast is even more marked: US\$2,464 for the Ford and US\$491 for the Mazda. With allowances made for the different product mixes of each company and differences in their vertical integration, the employee cost difference was reduced to US\$1,300.¹⁷ With further adjustment for tariffs and supplier costs, the final landed cost advantage of the Japanese producer in the late 1970s was about US\$1,400.

In response to competition from the Japanese machine tool industry, and its penetration and dominance of the CNC machine tool market, many

producers in industrialised countries have tried to maintain their profitability by moving into more specialised production, and have found so-called "niche markets". In the long term, there are likely to be many problems for these producers. Japanese firms are extending their product range into such areas, and, through their acquisition and establishment of manufacturing facilities in many industrialised countries, are able to supply special purpose machines and FMSs to these markets. Furthermore, the very close links which have been established by Japanese vehicle producers with several of the major vehicle manufacturers in the US and Europe also give their machine tool divisions considerable opportunities to supply machinery specific to that industry in these markets.¹⁸

The strategy of moving into a more specialised market in order to avoid direct competition with Japanese producers is not an option open to the Korean machinery industry, as it does not have the reserve of development, design and manufacturing experience on which this strategy was based by producers in industrialised countries. At present, the ability of Korean machine tool producers to compete against the Japanese in the least expensive sector of the world market is based on their lower wage rates. But Korean wage rates are now rising, significantly adding to overall production costs. And, in order for Korea to compete with Japan in the long term on the world market, Korean firms must follow the example of the Japanese by refining their production techniques. Although the application of Japanese manufacturing methods by the Koreans was not a part of this study, many firms mentioned their introduction and several had already established QCCs in an attempt to improve productivity and quality control. The implementation of JIT is, however, more difficult for Korean producers. The CNC machine tool industry relies on imported components, of which manufacturers must hold considerable stocks, as delays in delivery would halt production, and foreign orders have to be made and shipped in economic sizes. The potential for reducing expensive inventories is consequently far more limited. Only the establishment of an efficient supplier and sub-contractor network in Korea will enable JIT to be utilised to full advantage.

In the 1980s, many industrialised countries, with increasing manufacturing trade deficits, have become far more protective of their domestic markets and sensitive to penetration and expansion of market share by overseas producers. They have imposed restrictions, mainly on imports of Japanese goods, but also on imports from other industrialising and industrialised countries. The rise in protectionism against Japan has had benefits for Korean producers, as they have been able to exploit markets where Japanese competition has been limited.¹⁹ But industrialised countries have also become more alert to increased imports from NICs and more inclined to place restrictions on their imports before they gain a large market share. Japan's machine tool exports to the US were limited by a voluntary restraint agreement in late 1986: exports of machine tools from West Germany, Switzerland and Taiwan were also restricted at this time. Accompanying the limits imposed on these countries was a warning to Korea and six other countries not to increase their exports to the US to take advantage of reduced competition.²⁰ Korea has always been aware of such problems and has at various times entered early negotiations, mainly with the US, to try to avert trade friction. Korea has also opened up some of her markets at an early stage to forestall the US, Korea's largest trading partner and the destination of nearly 40% of Korean exports in 1986, from taking retaliatory measures (EIU, 1987a).²¹

The dramatic appreciation of the yen value in the mid-1980s has given Korea a competitive advantage over Japanese producers in some industries, particularly since the won has not increased in value at nearly the same rate. In the production of televisions, video recorders and microwave ovens, Korean firms have been able to capture a large share of the world market, while several Japanese producers have established or expanded offshore production facilities in the Asian NICs to reduce their manufacturing costs. The rise of the yen has not been entirely beneficial to Korean industry, as it has meant that Korean imports from Japan are much more expensive. In 1986, 34% of Korea's imports came from Japan, and Korea's trade deficit with Japan in the same year was US\$5.4 billion (EIU, 1987a: 22). Korea's main imports from Japan are capital goods and components, and these more expensive imports have, to

some extent, limited Korea's increase in competitiveness. In particular, for the CNC machine tool industry the rise in the value of the yen has meant that its major components, including control units, which are sourced in Japan, are now more expensive.

The implications of Japan's success are, of course, important for many other areas of industrial production and for the future success of many industrialised, industrialising, and developing countries. Japan's production methods are now being applied in many industrialised countries, with a view to improving their competitiveness and to attempting to recoup some lost markets.²² For developing countries, the increase in manufacturing productivity and factory automation in the industrialised world, including Japan, may deprive them of industrial opportunities by reversing the comparative advantage in the production of many labour-intensive items (Kaplinsky, 1984: 157-59). These developments also have a bearing on the continuing success of the NICs. Japan's competitiveness on world markets has two major effects on NIC exports. Firstly, Japan is no longer moving out of markets. Japan moved out of labour-intensive and polluting industries in the 1970s, but it shows no signs of restricting the overall exports of its vehicle, electronics, or machine tool industries. This means that while early NIC exporters could target industries which Japan and other countries were leaving because of high labour costs, no such openings are now occurring. And this has repercussions for other developing countries, as it means that the current NICs are remaining in labour-intensive industries longer, and fewer gaps into which other developing countries, such as Thailand, Malaysia and Indonesia, can enter are being created. Secondly, the export markets in which the NICs are having to sell are now highly competitive, and the major competitors are usually Japanese. When Japan commenced exporting items such as compact cars and CNC machine tools to the US and Europe, the competition in these markets was low and Japan was able to rapidly expand its market share by supplying high-quality but low-cost products. For the NICs, such rapid expansion of exports in these markets is now much more difficult, since competition is far more intense and the main competitors (principally Japanese) are unwilling to relinquish any of their market share. Korean firms have managed to penetrate some markets,

notably in electronic consumer goods (e.g., microwave ovens and VCRs), and they are making some headway in compact car sales (Manguno, 1989). In these sectors, the Koreans are attempting to compete mainly on price, although the Japanese appear quite able to meet such competition.

7.3 Taiwan: An Export-Orientated Machine Tool Industry

The Korean and Japanese materials analysed thus far support the view that the most important consideration influencing the development of machine tool industries is the size and structure of a domestic market. It must, accordingly, be pertinent to examine the machine tool industry of an Asian NIC whose domestic market differs radically from those of either Japan or Korea, and Taiwan offers a suitable case for such comparative assessment. The purpose of this section is, thus, not to present an exhaustive or definitive account of the Taiwanese industry, but solely to draw out relevant contrasts with Japan and Korea arising from its particular market and political environment.

There are several general structural features that characterise the Taiwanese industrial environment. The Taiwanese government has been less directive than either the Japanese or Korean government. Moreover, as a military consumer of industrial goods the Taiwanese government has had relatively little impact on domestic industries. The military establishment is distinguished by its comparative dissociation from civilian industries. Most Taiwanese manufacturing firms are small, independent, and family run. In marked contrast to Korea and Japan, there are few industrial conglomerates in Taiwan. Most importantly, Taiwanese manufacturing industry is highly export orientated.

These general structural circumstances also shape the environment for the national machine tool industry, and this section considers how this specific industry has developed within the limitations and opportunities provided by the Taiwanese setting. Why is it that Taiwan's machine tool industry – in many respects so successful – has acquired a relatively limited range of technological capabilities? The answer lays special stress on the character of relations between Taiwan's machine tool industry and its actual or potential consumers. Compared to the situation in both Japan and Korea, the Taiwanese machine tool industry has formed few technical links with users in the domestic market and is strongly orientated towards exports. Thus, the Taiwanese material will add further support to the argument developed in the Korean case-study:

the acquisition of sophisticated technological capabilities is highly dependent on close interaction between producers and users.

7.3.1 Historical Similarities

Like Korea, Taiwan, then a province within China, was occupied by Japan up to 1945. During Japanese occupation, Taiwan had a purely agricultural economy and supplied large quantities of rice to the Japanese empire. Thus, unlike Korea, there was no significant industrial activity in Taiwan before 1945. With the disintegration of Korea's industry between 1945 and 1950, and its final destruction in the Korean War, by 1953 Korea and Taiwan were similar in their almost total lack of established manufacturing industry. However, while Korea had lost most of its skilled managers and technicians— the occupiers who had returned to Japan in 1945— the number of qualified personnel in Taiwan increased dramatically, with the immigration of over a million and a half people from mainland China, who arrived with the Nationalist government led by Chiang K'ai-shek. While a large number of these immigrants were military personnel, a significant proportion came from China's technical and business community. With the installation of the new régime in Taiwan, and the establishment of the People's Republic of China (PRC) in 1949, mainland China and Taiwan separated. Each government, however, still formally claims sovereignty over the other. Taiwan sees the mainland as a military threat and a major preoccupation is its own security. Consequently, Taiwan, like Korea, maintains a huge standing army and associated military enterprises.

During the 1950s and 1960s, Taiwan and Korea were close allies of the US in its policy to contain the spread of communism in East Asia.²³ The US gave both countries considerable military assistance, including the training and equipping of large domestic armies, as well as economic assistance. The Nixon Doctrine of the late 1960s, and the closer relations between the US and the PRC, culminated in the diplomatic recognition of the PRC by the US in 1978 (after which Taiwan automatically severed its formal diplomatic relations with the US). This

situation forced Taiwan to reconsider its military relations with the US and promoted the build-up of an indigenous defence industry. Although Taiwan continued to get some military support from the US during the early 1970s, the government established new arsenals to supply its own forces and invested heavily in communications, armoured vehicles, and air-frames for jets. With the diplomatic recognition of the PRC, the US abolished its Mutual Defense Treaty with Taiwan and replaced it with the Taiwan Relations Act, which included an agreement to supply arms to Taiwan for purely "defensive" purposes. Following the introduction of this Act, Taiwan has been denied much of the military technology it has requested from the US, while the PRC continued its massive military investment, thus encouraging even more internal investment in Taiwan's defence sector.

Thus, like Korea, Taiwan perceived itself as pushed into developing its own military machine by changes in US policy. Taiwan's development of its own defence industry has, however, been very different from Korea's. While the expansion of Korea's defence industry was included in the overall promotion of the heavy and chemical industries, the promotion of Taiwan's defence industry was not. (Nevertheless, there has been a recognition by the Taiwanese government that it needs to develop the country's technological base to support its military institutions.) The Taiwanese defence industry was, until the early 1980s, totally owned and operated by the government; unlike Korea, no part of production was the preserve of civilian industry. So far as machine tools are concerned, the military has the capacity to produce a small amount of its own requirements in-house, but depends overwhelmingly upon foreign imports. The civilian sector is therefore almost wholly separated from a local military clientele. The dissociation of these two areas of production has meant that several of Taiwan's industries have not been able to benefit from economies of scope in the combined production of similar defence and civilian goods. For example, while in Korea the manufacture of some military vehicles and artillery was contracted out to the *chaebol* vehicle producer, Kia, specialising in small van and truck production, in Taiwan production of all ground-force equipment, including artillery and military trucks, has been undertaken by government-run facilities, with only very

limited sub-contracting to private firms. Consequently, possible economies of scope and economies of scale, which may have been achieved by manufacturing these items within the civilian vehicle sector, have been denied to both the defence and civilian industries.

7.3.2 Taiwan's Economic Growth, Its Machine Tool Industry and Main Markets

Like Japan and Korea, Taiwan has experienced very rapid and sustained economic growth since the early 1960s. The annual growth of Taiwan's GDP averaged 8.7%, in real terms, between 1952 and 1985 (EIU, 1987c: 9). In 1985, Taiwan's per capita GNP was significantly higher than Korea's - US\$3,444 to US\$2,129 - though, of course, much lower than Japan's.²⁴ From the 1950s, the Taiwanese economy has changed from one principally based on agriculture to one dominated by manufacturing. Since the early 1960s, an important feature of Taiwan's growth has been its exporting, and an export orientation continues to characterise the economy: in 1985, exports accounted for 56% of GDP (ibid.). Taiwan, like Korea and Japan, has virtually no natural resources: nearly all exports are manufactured goods, while a large proportion of imports are raw materials and oil. Taiwan's economy has gone through three distinct phases during its rapid development. In the 1950s, agricultural growth was promoted and most industrial development was geared towards import substitution. US economic aid was also an important factor in Taiwan's development at this time. During the second development phase, in the 1960s, exports of low-technology products and assembled consumer goods, utilising imported components, were encouraged.

More recently, as wages have risen, eroding the country's competitive advantage in labour-intensive production, Taiwan has entered its third development phase, with most growth occurring in technology- and capital-intensive industries, combined with import substitution of some materials and components used in export goods.²⁵ Although the more technology-intensive industries are growing, textiles (garments, fabrics and yarn) and shoes continue to be major export items: in 1986, they

accounted for almost a quarter (by value) of Taiwan's exports. The most important export sector in the technology-intensive industries is electronics, mainly consumer electronics goods, which accounted for 17% of exports, while metal and plastic products made up 6% and 4% respectively (EIU, 1987d: 2). As already noted, the structure of manufacturing industry in Taiwan is characterised by a large number of small family-run firms, and there are few large firms or conglomerates. In the early 1980s, nearly 60% of value added in Taiwan originated in firms with less than 300 employees, and employment in manufacturing units with ten or fewer workers accounted for approximately 70% of all jobs (Harris, 1986: 48).

Of the NIC machine tool industries, Taiwan's has had most impact on international markets, principally because of the very high levels of its exports to industrialised countries, and especially to the US. In 1983, Taiwan became the third largest source of imported machine tools in the US (NMTBA, 1985: 128). Taiwan's success in the US market has also meant that its exports to the US (like Japan's) were limited by a "voluntary" restraint agreement in December 1986. Taiwan ranked 14th in world production in 1985, and, as such, is one of the largest NIC producers; in this year, it was the 10th largest exporter in the world and was the largest NIC exporter. However, Taiwan is a fairly small consumer of machine tools; in 1985, it was only the 19th largest consumer, and its consumption of machine tools was approximately half that of Korea (American Machinist, Feb. 1986: 89). If the machine tool consumption of Korea and Taiwan is compared in relation to their respective populations, the "per capita" consumption of machine tools in each country is similar (Korea's population being approximately double that of Taiwan's). If, however, machine tool consumption is compared to the component of GDP originating in manufacturing, then Korea is proportionately a much larger consumer than Taiwan.²⁶ Korea's investment in new machine tools for its manufacturing industry is, therefore, at a much higher level than Taiwan's.

Although Taiwan's machine tool industry had its origins in the late 1940s and 1950s, production became significant, and the industry expanded,

in the 1960s in line with the economic growth experienced by the whole economy. In particular, the industry benefitted from increased domestic demand created by the expanding export producers, especially those such as sewing-machine and bicycle firms, but other light industries also helped enlarge domestic demand. Manufacturers of electrical appliances bought basic drill and punch presses and the textile industry also secured some of its machinery domestically. Taiwan's manufacturing environment is still dominated by light industries, and these continue to be the major domestic consumers of machine tools.

Machine tool manufacturers typically had two origins: small repair shops which began to manufacture copies of the machines they repaired, and textile machinery producers which used their existing skills to expand their range of machinery output. In one respect, the machine tool industry which developed in Taiwan from the mid-1960s resembled general global patterns: a relatively large number of small firms and a few quite sizeable companies. In the mid-1960s, only 20% of machine tool firms in Taiwan had more than 20 workers. Whether large or small, all Taiwanese machine tool producers displayed high levels of vertical integration. During the 1970s and early 1980s, the Taiwanese machine tool industry has become rather more concentrated. One conglomerate has entered machine tool production and the larger producers have become relatively more important. Nevertheless, the basically dual structure of Taiwan's machine tool industry persists; in 1973, over 50% of firms still had less than 20 employees while a few had more than 100. Of the 200 Taiwanese firms manufacturing machine tools in the early 1980s, only 64 employed more than 50 workers and, of these, only 25 had over 80 employees (Amsden, 1977: 223; 1985: 276; Asia Research Bulletin, 30 June 1980: 693). The larger firms, however, now account for a very significant proportion of total output. The fifteen major producers forming the Precision Machinery Development Association of Taiwan together manufacture between 60% and 70% of total Taiwanese machine tool output (Metalworking, March 1987: 24). The biggest of the Taiwanese producers employed over 500 workers in the mid-1980s, which, although large by NIC and Taiwanese standards, is small in comparison to the larger Japanese manufacturers.²⁷

Thus, while the Taiwanese machine tool industry resembles Korea's with respect to concentration and distribution of firm size, there is one major and highly consequential difference. In Korea, membership in a conglomerate structure is a significant feature of the environment for machine tool producers, while in Taiwan only one firm is part of such a group. This one firm excepted, all the rest of Taiwan's machine tool producers are independent.

The machine tools being manufactured in the 1960s were very basic and of low quality: their estimated life span was only two years. Consequently, domestic consumers requiring higher quality machine tools imported the machinery they needed.²⁸ Although the Taiwanese machines were of poor quality compared to those sold by the developed countries, they were nevertheless adequate for basic metal cutting and their low price compensated for their deficiencies. Demand for this type of machine expanded generally in Southeast Asia during the 1960s, and Taiwan increased its exports to meet this demand (see Amsden, 1977 for a more detailed examination of this market). By the late 1960s, Taiwan was exporting about 50% of its total machine tool production, principally to Thailand, South Vietnam, and the Philippines.²⁹ Machine tool production and exports continued to grow rapidly in the early 1970s; the value of total production rose from US\$10 million in 1970 to US\$33 million in 1975, and exports, still principally to the markets of Southeast Asia, grew from US\$6 million to US\$19 million for the same years. Again, the low quality of the machines was not seen as a drawback by buyers in these markets. Typically, these buyers had a limited budget and wanted a quick return on their investment. As long as the machines were adequate to manufacture their products, then cost was the main consideration (Jacobsson, 1986: 146-48; Amsden, 1977: 220-26).

Even with its perceived low levels of quality and technical development, the Taiwanese machine tool industry continued to expand rapidly in the late 1970s and early 1980s. Exports also continued to increase. Most notably, exports to developed countries grew from the mid-1970s. Table 7.2 shows Taiwan's production and trade statistics for 1976 to 1985. Of special significance in these figures are the very high

levels of machine tool exports and imports. Overall, Taiwan has been a net exporter of machine tools since 1977, and it exports an extremely high proportion of its total output (between 64% and 86% of total machine tool production in the years covered). In comparison, in 1985 Japan exported 40% of its total production, West Germany 60%, and Korea a mere 14% of its output (American Machinist, Feb. 1986: 89). However, Taiwanese industries have continued to rely on imports for a very high proportion of their domestic machine tool consumption: between 57% and 86% of total domestic consumption was imported in the years covered.

Table 7.2 Taiwan Trade Statistics for Machine Tools (Cutting and Forming)

Year	Production (P)	Imports (I)	Exports (E)	Consumption (C=P+I-E)	P C	I C	E P
	<-----in million US\$----->				<-----(as %)----->		
1976	35,0	35,7	30,0	40,7	86	98	86
1977	58,3	35,7	49,8	44,2	132	81	85
1978	126,0	58,3	94,0	90,3	140	65	75
1979	198,0	91,4	144,3	145,1	136	63	73
1980	245,1	125,1	178,3	191,9	127	65	73
1981	249,4	99,2	182,6	166,0	150	60	73
1982	185,6	79,7	124,4	140,9	132	57	67
1983	204,9	109,8	131,5	183,2	119	60	64
1984	244,1	118,6	172,5	190,2	128	62	71
1985	261,5	112,4	208,9	165,0	158	68	80

Source: American Machinist (compiled from various issues).

From 1975 to 1981, the latter being a peak year for Taiwan, machine tool production increased seven times in value, and exports increased six times. In particular, this rapid growth of production and exports was

attributed to the growing demands of the US market, which became Taiwan's major customer (Amsden, 1985: 275; Jacobsson, 1986: 149). The industry suffered severely in 1982, a year in which global production declined by more than 20% and the global market was depressed. Taiwan's exports were reduced by 30%, domestic consumption also fell by 15%, and domestic production declined by 25% (American Machinist, Feb. 1983: 77).³⁰ While Taiwanese producers had benefitted considerably from the growth of their main export markets, they were severely affected when these markets were depressed. Furthermore, the cycles of demand in Taiwan's export markets had an amplified effect on the rates of growth and contraction of Taiwan's machine tool production. Output recovered from the low levels of 1982, and, by 1985, exceeded the high production and export levels set in 1981. Domestic consumption also rose from its low in 1982. In part, this increase came from the machine tool industry itself which began to re-tool in anticipation of increased domestic demand following announcements that a major Japanese company was to commence large-scale vehicle production in Taiwan (Metalworking, July 1985: 13).

The direction of Taiwan's exports changed in the 1970s, from a dominant orientation to other developing Southeast Asian countries towards an increasing focus on developed country customers. The majority of growth took place in exports to the US, from US\$2.7 million in 1975 to a peak of US\$102 million in 1981. Subsequently, the value of Taiwan's exports to the US has stabilised at around US\$90 million. During this period of growth, the US market became the largest foreign consumer of Taiwanese machine tools, and in 1980 and 1983 took 60% and 54% respectively of Taiwan's exports (Amsden, 1985: 275; NMTBA, 1986: 232). Although Taiwan has become the third largest exporter to the US, the levels of its exports are fairly small in comparison to the two leading exporters to that market, Japan and West Germany.³¹

This change in export destination has been discussed by both Amsden and Jacobsson. Amsden (1985: 275-76) suggests that the re-orientation was to a large extent forced on Taiwanese producers because demand in Southeast Asia was declining with the end of the Vietnam War, and competition in the reduced market was increasing due to the entry of new

producers (e.g., the PRC, India, and Eastern Europe). Alternatively, Jacobsson (1986: 148) argues that a major influence on this change of export destination stemmed from a visit to Taiwan by a group of US distributors looking for producers of cheap machine tools. The change that did take place was arguably the result of a combination of these two factors; Taiwan needed to find new markets if it was to continue to grow and was fortunate that a new market was then opening up. Importantly, the distributors had sales networks in the US, thus enabling Taiwanese producers easily to enter that market. The establishment of trading links with a new export market can be very difficult and costly for small NIC firms. However, as Amsden (1985: 276) perceptively notes, this transition would not have been possible for the Taiwanese industry without its accumulated technological experience and the profits gained through its exports to Southeast Asian countries, resources which were then used to finance new investment.

Although the distributors established sub-contracting relationships with Taiwanese producers, supplied technical information on the design of machine tools, and persuaded producers to invest in some higher quality machinery, the machines being exported were still low-value, basic conventional machines with only marginally improved quality. Exports were also concentrated in a few types of basic machine tool; in 1980, five types (bench lathes, high-speed lathes, bench drilling machines, vertical milling machines, and band saws) accounted for 73% of total exports (Amsden, 1985: 274). Some of the larger exporting firms, having established a niche in the US market, and having built up a reputation among small machine tool users by selling through various distributors, have established their own sales networks in the US, and one firm has even built its own US assembly plant.³²

When the fieldwork for this study was undertaken in July 1985, the Taiwanese machine tool industry was in a depressed state compared to the growth and expansion that had taken place since its previous slump in 1982. There were three reasons for this. Firstly, investment in the domestic market was depressed, due to high Taiwanese interest rates. Secondly, the expansion of the domestic market anticipated by producers

with the news that large-scale Japanese car production would commence in Taiwan did not materialise. (The Japanese firm, Toyota, withdrew following a disagreement with the Taiwanese government over export requirements (King, 1986a).) Several machine tool builders had borrowed heavily to import precision and sophisticated equipment to be in a position to supply machinery to the proposed vehicle and vehicle component industries, and so, with a depressed market and high interest burdens, many of them were experiencing considerable financial difficulties. Thirdly, exports were adversely affected by continuing trade friction with the US.³³ The depression was, however, only a short-term one. Production of machine tools by Taiwan rose to US\$367 million and US\$579 million in 1986 and 1987 respectively, and exports to US\$261 million and US\$378 million for the same years (American Machinist, Feb. 1988: 63). Nonetheless, Taiwan's machine tool exports to the US have been restricted. The voluntary restraint agreement of December 1986 limited Taiwan's share of the conventional milling machine and lathe markets in the US to 1981 levels, and their share of the US CNC lathe, milling machine and machining centre markets to 1985 levels. Taiwan also agreed not to change its export product mix by increasing the number of higher-value products. These limits were set to operate until 1991 (Wall Street Journal, 17 Dec. 1986: 4).

Growth of CNC Production

In the mid-1970s, a few Taiwanese producers started to develop and produce CNC machine tools. The production, import, export and domestic consumption of these machines is summarised in Table 7.3. CNC production has become a more important part of Taiwan's machine tool output: the ratio of CNC machine tool production to total machine tool output was less than 5% up to 1982; in 1983, 7% of production came from CNC; in 1984, this proportion almost doubled to 13%, and had reached 15% by 1985.³⁴ In 1984, all the CNC machine tools being produced were lathes, milling machines, or machining centres. Of total CNC production, 45% were machining centres, 42% were lathes and 12% were milling machines. (Between 1980 and 1984, nine CNC boring machines were manufactured, but

their value was insignificant compared to the value of the other three types of machines.)

Table 7.3 Taiwan's CNC Machine Tool Production and Trade Statistics
(in 10,000 NT\$; units in parentheses)

Year	Production (P)	Imports (I)	Exports (E)	Consumption (C=P+I-E)
1976	891 (7)	4,832 (20)	505 (4)	5,218 (23)
1977	1,838 (14)	7,665 (25)	1,160 (9)	8,343 (30)
1978	5,985 (44)	13,979 (37)	3,952 (31)	16,012 (50)
1979	15,728 (113)	34,245 (101)	9,603 (84)	40,370 (130)
1980	25,556 (176)	46,327 (126)	14,652 (116)	57,231 (186)
1981	36,318 (262)	40,998 (120)	21,423 (150)	55,893 (232)
1982	38,875 (229)	48,208 (113)	26,657 (165)	60,426 (177)
1983	56,224 (396)	72,453 (162)	35,564 (254)	93,113 (304)
1984	128,808 (1061)	89,032 (213)	66,692 (675)	151,148 (599)

Source: Figures supplied by ITRI, Taipei.

As with its conventional machine tool output, Taiwan's CNC machines have low average values compared to those manufactured in most other countries. In 1984, the average values of CNC lathes and machining centres were about US\$40,000, and the average unit value of CNC milling machines was US\$11,000.³⁵ In comparison, Japanese CNC lathes and machining centres had an average value of US\$63,000 and CNC milling machines an average value of US\$53,000 (NMTBA, 1986: 200).

The major contrast to Korea's CNC output is the large proportion of Taiwan's production destined for export: in the years from 1980 to 1984, between 51% to 70% (by value) of Taiwanese CNC machine tools were exported. Just as the Taiwanese machine tool industry became an exporter of cheap and basic conventional machines in the 1970s, in the 1980s it

became an exporter of cheap CNC machines. (The average unit value of exported machines was similar to that of overall production.) CNC machine tools are becoming a more important feature of Taiwan's machine tool exports: in 1980, they accounted for 2% of total exports by value; in 1982, this increased to 6%; and in 1984, to 10%. As with conventional machines, developed countries are the major destination of Taiwan's CNC exports. Unfortunately, the export figures by destination for lathes and milling machines are not broken down into conventional and CNC categories, but the export destinations of machining centres are available. In 1983, 89 of the 94 machining centres exported went to industrialised countries: 48 went to the US and 38 to Europe (of which 17 went to the UK); a further two were sold to Australia and one went to Canada (NMTBA, 1985: 231-32). (There is little reason to suppose that the export destinations of other types of CNC tools are radically different.)

The structure of Taiwan's imports of CNC machine tools also closely follows the pattern set by its imports of all types of machine tools - imported CNC machinery having very high unit value in comparison to machinery produced and exported by Taiwan. In 1984, the average unit values of imported CNC lathes, CNC milling machines, and machining centres were US\$63,000, US\$154,000 and US\$164,000 respectively. Most of these machines were imported from Japan; other large supplier countries were West Germany, the US, and Switzerland. Again, the only precise data on the origins of imported CNC machine tools are available for machining centres. In 1983, Taiwan imported 39 machining centres, of which 36 were Japanese, two were American and one Swiss (NMTBA, 1985: 230). The domestic market, therefore, continues to import the high-value machinery it requires, since this is not produced indigenously. In terms of units, Taiwan is now a net exporter of CNC machine tools; however, in terms of value, Taiwan remains a net importer.

Taiwan's export orientation arises largely from the structure of its domestic market. While in Korea and Japan a large proportion of demand originates in the vehicle industry and its component manufacturers, in Taiwan most machine tool users are small firms in light industries, which require standard, basic, and cheap machines. The machinery requirements

of these firms are irregular, and, individually, their consumption is very low. Consequently, there is no reason for such small firms to form technological links with machinery producers. There is no single large domestic machine tool consumer with which machine tool firms could effectively collaborate. The vehicle industry in Taiwan consists of six joint-ventures assembling vehicles from imported and locally-produced parts to the designs of their foreign parent companies. And the requirements for more sophisticated machinery by the defence sector are met overwhelmingly by machine tool imports. Only the single conglomerate firm has been able ^{to} establish significant links with domestic machine tool users with whom it can collaborate in the development of new or special purpose equipment.³⁴ None of the other firms, large or small, has been able to form such ties with any domestic industrial sector.

Nor have Taiwanese producers been able to establish close links with their users in export markets. On foreign markets, a large proportion of Taiwanese output is sold through dealerships, and for many producers these dealers have been an important source of technical and market information. Several of the larger exporters have now established their own foreign sales networks through which information is similarly transferred back to the firm. While technical information on the changing requirements of producers in the main export markets is thus communicated back to Taiwanese machinery producers, they do not have any direct technological links or feedback from their foreign users. The high levels of exports mean that Taiwanese producers are affected, both favourably and adversely, by changes in global demand, and especially by market changes in the US. These influences have had more effect on the prosperity of the Taiwanese industry than have changes in demand from its own domestic market.

7.3.3 Government Policy and the Taiwanese Machine Tool Industry

In comparison to the machine tool industries of Korea and Japan, the Taiwanese industry has received relatively little specific government promotion. All manufacturers, regardless of industrial sector, were given government export subsidies from the late 1960s (Amsden, 1985: 281). According to Jacobsson (1986: 151), this support declined in the 1970s, giving exporters only a marginal subsidy, or only compensating them for increased costs caused by some import controls, and, in effect, yielding no net subsidy. Exporters in Taiwan were, therefore, in a similar situation to those in Korea which were operating in a virtual free-trade environment.

In the early 1980s, at a time when the indigenous defence industry was being built up, the Taiwanese government did introduce certain limited measures to promote the development of chosen "strategic" industries and to accelerate the structural transformation of Taiwanese industry.³⁷ The selected industries were all low energy users, high value-added manufacturers with high linkage effects and high skill content. In total, 150 products were so listed, including CNC machine tools, FMSs and CAD systems. Four measures were used to promote these industries: higher tariffs, provision of risk capital, incentives for exports, and support of industrial R&D. Tariffs on imported machine tools were increased from 10% to 20%; however, this level was only set for a limited period of three to five years in order to give producers the opportunity to exploit the domestic market and increase their production volumes. Risk capital to a total of US\$250 million was provided by the Bank of Communication to various industrial projects, at 2% below base rate, but only up to 65% of the total capital required. However, as so many different product areas were covered, this was only a very small amount of money per product, and a large proportion of the finance allocated by this scheme went to the shipbuilding industry, which was also the main recipient of subsidised credit allowed to exporters through the Export-Import Bank. This bank ran other schemes for the benefit of exporters, including loans to foreign institutions (to be re-lent to the purchasers of Taiwanese equipment), an export insurance scheme (financing

exporters before they actually shipped the goods), and import credits (to help with the purchase of raw materials). While all these schemes included the machine tool industry, their effectiveness in promoting the development of that industry is unclear. Only a few of the producers interviewed by the author felt that they had benefitted from these measures. And one interviewee remarked that the government's measures were principally in the form of "psychological" support and were of little practical use to individual firms.

Although there was slight specific promotion, there was a measure of protection of the machine tool industry. Tariffs and import licensing were introduced and applied to control machine tool imports. Some machine tools could be imported duty-free, and, for others, tariffs were low. The nominal tariffs for importing conventional lathes were 13% in the 1970s and 15% for CNC lathes in the early 1980s. Given the high proportion of Taiwan's domestic consumption met by imported machine tools, the licensing system evidently presented no substantial obstacles. However, imports by machinery distributors and from certain countries were restricted. Significantly, these countries included Japan, Korea, and Hong Kong, so that Taiwan's main competitors on export markets and those which could most effectively compete with domestic producers on the Taiwanese market were practically excluded from this market (Jacobsson, 1986: 151; Amsden, 1985: 282). Furthermore, the licensing system prevented the importation of machinery similar in price and quality to that produced domestically (Fransman, 1986a: 199). Thus, like Korea and Japan, the Taiwanese domestic market was effectively protected in sectors in which the indigenous industry was most at risk from foreign competition and this protection was applied in such a way that domestic users were not disadvantaged.

The Taiwanese government's most direct influence on the machine tool industry has been through its support of technological development. The Metal Industry Research Laboratories (MIRL) were originally founded in 1969 to undertake research in metallurgy, materials science, mechanical engineering, and industrial management, and in 1973 ~~they were~~ combined with other institutes under the umbrella of the Industrial Technology Research

Institute (ITRI). In 1977, a machine tools centre was created on the Hsinchu campus of MIRL, and it is here that development work on machine tools, including CNC and automated machinery, is undertaken. There are over 200 researchers and engineers at this centre, of which almost half are in electrical, electronics, or controls disciplines. MIRL offers technical and design support to Taiwanese machine tool producers, and it played a key role in the early introduction and development of CNC machines in Taiwan. MIRL sent some of its engineers abroad for training in CNC technology, and also imported three CNC machines for its own use. These machines were shown and demonstrated to producers at local machinery exhibitions, as well as being experimented upon (Jacobsson, 1986: 166). With this basic stock of knowledge on the operation, production, and design of CNC machine tools, MIRL has subsequently entered collaborative development projects with many Taiwanese producers. By 1983, a total of 22 machines had been designed by MIRL, in collaboration with 18 firms (Fransman, 1986a: 197). Each firm pays MIRL a lump sum and a royalty for its work on new machine designs, but these do not cover all the development costs, and new designs are, therefore, subsidised. (In total, firms pay approximately 60% of development costs, and the government pays the remainder.) At the end of the project, all the blueprints and assembly diagrammes for the new machine are given to the firm, along with supplier lists for all critical components. MIRL also undertakes national projects involving several firms, which attract much higher rates of government subsidy. These projects have included the development of control units, robots, and FMSs. Finally, MIRL also does project work for machinery users, designing several special purpose machine tools specifically for user firms.

The scope of MIRL's work far exceeds that of most countries' government-supported research institutes: as well as aiding firms in their product development and the manufacture of prototypes, it also, by its provision of certain specialised equipment, acts as a sub-contractor to the machine tool industry. For example, MIRL has a well equipped heat treatment plant which machine tool producers can use; it makes precision gears which are supplied to the industry; and it also has a large CAD centre offering manufacturers training and design support. MIRL is a

much bigger organisation than that its current Korean equivalent (KIMM), and has been far more successful in its technical support of domestic producers than the corresponding Korean institutes. However, because of the large size or *chaebol* links of Korean producers, they have been able to build up quite large and effective design departments. But the comparatively small scale of Taiwanese firms has meant that they have been handicapped in acquiring significant design capabilities. Consequently, technical support from government continues to be crucial in Taiwan, whereas in Korea most producers have now developed to a point where they have design self-sufficiency.

7.3.4 Technological Development in the Taiwanese Machine Tool Industry

Although machine tool output and exports grew dramatically in the early 1970s, the Taiwanese industry made few technical advances. Amsden (1977: 230) concluded that the technological development of the industry up to 1974 was not a "monumental achievement", pointing to five faults in production which curbed quality improvements. These included the lack of investment in specialised machinery and heat treatment, the use of low-grade castings (even though better foundries could have been used), a lack of standardisation, and the absence of quality control in production. Moreover, with cost as the principal consideration, she saw little prospect of any of the firms increasing the quality of their output: any investment in better machinery or higher quality materials and parts would result in higher production costs and reduced competitiveness.

Amsden (1977: 221) suggested that one reason for the lack of technological development in the Taiwanese machine tool industry in the early 1970s was the absence of close technical links between sophisticated machine tool users and producers. Domestic users, including the defence sector, continued to import complex and high-precision machinery. The defence sector manufactured a small number of its own machine tools, with foreign technical support, but, because of security considerations, technology was not transferred to the private (civilian)

sector. Similarly, government-owned shipyards and large machinery works were self-contained. There was therefore no technology transfer or stimulation for the domestic industry from the local sophisticated machinery users. Moreover, Amsden believed that the structure of the machine tool industry in Taiwan also impeded its technical development. Although by the mid-1970s a few larger firms had evolved, the majority of firms were still very small, highly vertically integrated, with a low degree of specialisation. These circumstances resulted in low utilisation of production equipment, especially in the foundries connected to many of the firms, the dispersion of skills over a wide range of jobs, and complex management. Even the larger producers were highly vertically integrated and undertook production work which in many other countries would have been sub-contracted to smaller specialist support firms.

By the early 1980s, the Taiwanese machine tool industry had undergone significant changes (Amsden, 1985). Since the early 1970s the industry had entered the production of more complex tools, including CNC machines, and had marginally raised its quality levels. As already noted, the industry had become slightly more concentrated and several large manufacturers had evolved. A sub-contractor and specialist producer network had now emerged; many of these were, in fact, machine tool producers which had integrated backwards into the large-scale manufacture of parts. This also included MIRL which had established its heat treatment facility and precision gear production to support the industry. These changes were the result of a number of different factors, including increased technological effort by the larger firms, technical support given by MIRL, importation of new production equipment (which provided models for new products as well as improving production quality), and advice from US distributors.

The Taiwanese machine tool industry began the development of CNC machines in the mid-1970s, acquiring the capabilities for this entry from a variety of sources. Unlike Korea or Japan, licensing agreements were not used to acquire the new technology: by 1985, a total of 36 firms were making CNC machines, of which only one, the single firm which belonged to a conglomerate, had entered a formal technology agreement. A main source

of technology for the development of CNC machine tools came from imported machines which were copied.³⁶ The learning process involved, however, was not simply crude copying, as adaptive innovations were included in the resulting designs. For example, one engineer interviewed by the author in 1985 stated that his firm had taken features from several imported CNC machines and combined these ideas in its own model. For most of the manufacturers visited in 1985, copied machines still formed the main bulk of their output. And in these cases foreign machines are still used as the base for new product developments. As well as introducing new design concepts to the firms, imported machines also helped them raise their productivity and the quality of their final products.

The design and production support offered by MIRL was crucial to many Taiwanese firms. Researchers at MIRL helped to diffuse CNC technology among machine tool producers, both through direct collaborative projects and by exhibiting MIRL's imported CNC machines to users and producers. A small number of larger Taiwanese firms now have adequate design capabilities to develop their own new CNC models, and a few have already successfully designed complex CNC machines, including four-axis CNC lathes and machining centres with ATCs. However, most Taiwanese firms only have the capabilities to copy machines or to adapt and modify their existing products, and for these manufacturers the development of new models can only be undertaken with the technical support of MIRL.

In the design of interfaces, machine tool firms were helped by two agencies. Firstly, as in Korea, the Japanese controls manufacturer Fanuc supported Taiwanese firms in their technological developments, offering training and technical support (Fransman, 1986c: 1384). Secondly, the technical support given by MIRL included interface design. However, unlike Korea, there appears to have been some initial difficulty in the purchase of controls by Taiwanese producers. One producer observed that when his firm first developed a CNC machine tool in 1974-75, it initially approached Fanuc, but Fanuc refused to supply the company with the tiny quantities it then required, and so the firm purchased controls from the US. Later, Fanuc did agree to supply the firm with controls and has

remained its sole supplier. Another firm noted that it too initially had difficulties in finding foreign suppliers for major components, the control unit, DC servo-motors, and ball screws. Having established contact with a suitable supplier, the firm experienced further problems with the importation of the components. Importantly, for firms which collaborated with MIRL on the development of a new machine tool, such problems were eliminated as a list of component suppliers was supplied along with the design and production instructions.

Machine tools manufactured in Taiwan have typically been cheap and of low quality. In the mid-1980s, a few of the larger manufacturers visited were anxious to improve the quality of their output. In part, this move was in anticipation of an increase in domestic demand for higher quality machines, but it was also in response to increasing competition in this product area on international markets from other NICs. In order to improve quality levels, a few firms had imported new machinery. This included large sophisticated machine tools from West Germany and Japan, very high-precision machinery (e.g., jig borers) from Switzerland and the US, and coordinate measuring machines from the UK.

In the early to mid-1980s, one firm in the Taiwanese machine tool industry stood out as a technological leader (Jacobsson, 1986: 154-59). Alone among Taiwanese companies, Yang Iron systematically started to design and manufacture more highly automated systems, while it had for some time been producing more complex CNC equipment. Accordingly, a brief analysis of this firm's experience in entering the "top-end" of the CNC machine tool market permits a more detailed analysis of the possibilities and problems posed by the Taiwanese industrial environment. The experience of Yang Iron shows how Taiwanese producers can relatively successfully acquire more sophisticated technological capabilities, including design capabilities, while it also highlights continuing problems for that acquisition and consolidation thrown up by the nature of the domestic market.

Yang Iron originated in the 1940s as a textile machinery manufacturer, entered machine tool manufacture in the mid-1960s, and by

the late 1970s was one of the largest machine tool manufacturers in Taiwan. It subsequently ceased manufacturing textile machinery, but in 1977-78 entered a new area of production, fork-lift trucks. In 1985, the firm had a total of 800 employees (in both machine tool and fork-lift truck manufacture) and is therefore large by Taiwanese standards. The firm started exporting to the US in the mid-1970s after being contacted by an American distributor, and it continued to export through this distributor until 1982, when it established two branch offices in the US, in which year it also set up a Japanese branch office. In the early 1980s, Yang Iron was the leading Taiwanese exporter of lathes and was one of the top three exporters of machining centres (Metalworking, March 1985: 62). In 1984, over 50% of its total machine tool production, by value, was exported, principally to the US, but exports to Japan and West Germany were becoming increasingly important.

Yang Iron retro-fitted one of its engine lathes in 1974 (the first CNC development in Taiwan), but only a few of these machines were produced and most were used within the firm's own production plant. This machine was re-designed and improved in the following year. A new CNC lathe was further developed in 1980 and two more CNC lathes, on similar lines, were designed in 1982 and 1984. All three of these later lathe developments were purpose-designed CNC machines with two-axis control and one had a slant bed. In 1979, the company commenced production of a rudimentary vertical machining centre and in 1980 an ATC was added to this model. In 1982, a horizontal machining centre was developed and two more vertical machining centres, of a similar design to its earlier model, were added to the range in 1984. The three CNC machines introduced in 1984 were intended, according to a director, to "integrate the product series", thus giving the firm a complete range of machining centres and CNC lathes. By 1985, the manufacture of these seven models accounted for about 60% of the company's output.

Yang Iron's acquisition of CNC design capabilities has been a lengthy process; in CNC lathe production it took the firm at least eight years to progress from the production of a retro-fitted lathe to a complex one. Its developments in machining centres were more rapid, but these used the

base of skills which had been built up in lathe design. The firm has a large design department of 40 employees, including ten core designers and five electrical/electronics engineers. The work undertaken by this department is entirely in product development; virtually no custom design work is done and the firm does not develop or make any special purpose machines.

As well as designing a complete range of CNC machine tools, Yang Iron has also developed and used automated equipment. In the late 1970s, the firm bought a CAD system. The training of personnel to work on the system was undertaken by an engineer from the foreign supplier, who worked at the plant for about two months. The firm estimated that it took about four years for the system to become fully operational and cost effective. During this time, a data base was built up incorporating the designs of existing products and their components. In this process approximately 75% of the components used in different models of machines were standardised, and these can be easily re-called and incorporated into new designs, giving the firm substantial savings in time and money in such developments.

In the early 1980s, Yang Iron developed several automated production systems and was also a collaborator in automation projects undertaken at MIRL. The firm made a fairly basic FMS with two machining centres and installed it in its own plant. An automated warehousing system, with computerised stock control, was designed and installed in the machine tool plant. A basic pick-and-place robotic arm, attachable to its lathes to transfer parts, was also added to the firm's product range. (A hydraulic system was used to control the movement of this arm rather than a more expensive servo-system, and the arm was activated by a programmable controller with very limited memory.) All of these developments were undertaken with the aim of becoming a supplier of automated factory equipment; however, only a few robotic arms had been sold by 1985 and there had been no buyers for either the warehousing system or the FMS.

Having successfully undertaken these ambitious projects, Yang Iron found no domestic market for their developments. The resulting economic

problems were exacerbated by more general difficulties confronting the Taiwanese industry in 1985. In that year, the firm was declared bankrupt and was obliged to reconsider its product strategy. Yang Iron was being assisted at this time by a national bank under the Corporation Rehabilitation Act. Following the implementation of a rescue plan, the firm laid off about a third of its employees, sold off some unprofitable divisions, and changed its production strategy. Machine tool production was now to be concentrated solely on the manufacture of general purpose machines, and all plans to manufacture more automated systems were abandoned (Metalworking, Nov. 1986: 152-54).

The experience of Yang Iron in this enterprise shows that some of the larger Taiwanese machine tool producers do indeed have the skill-base to enable them to acquire significant design capabilities in the more sophisticated part of the CNC market. Nevertheless, the environment in which they operate makes the consolidation of these capabilities and their effective application in an economically viable production strategy extremely difficult. At present, there is hardly any sector of the domestic market into which such machinery can be effectively sold. Yang Iron's products were too sophisticated for its domestic market, and, because of the high levels of user-producer consultations and discussions which need to take place during the development of FMSs and automated warehousing systems, sales to foreign markets were impossible.³⁹

The career of Yang Iron notwithstanding, the acquisition of design skills by the Taiwanese machine tool industry in general has been an arduous and lengthy process, which ultimately may be limited by structural considerations. Taiwanese producers have principally built up their design capabilities through innovatively and adaptively copying imported models— a process which indeed does require high levels of technical understanding and skill. This type of learning has been highly effective in building up adequate capabilities to develop and manufacture narrow ranges of standardised products. However, even in the most technically advanced firms, the main design work undertaken is the introduction of incremental changes to existing models. None of the major Taiwanese machine tool producers undertake any significant custom

design work or manufacture special purpose machinery. The design and development capabilities that have been built up by Taiwanese firms are, therefore, those of adept and quick technology followers.

The build up of skills in CNC production has taken Taiwanese firms many years. In comparison to Korea, the Taiwanese industry in 1985 probably had slightly higher capabilities in the design of standardised CNC machine tools, but considering that many of the Taiwanese producers entered the industry in the mid-1970s, about five years earlier than most of the Korean producers, their build up of skills has been slower. Arguably, the shorter time taken by Korean producers to acquire design and production skills is due to their active use of formal technology transfer agreements and a much higher level of personnel transfer with foreign firms.

Amsden's first study (1977: 221) emphasised disadvantages arising from the lack of close contact between machine tool producers and the more sophisticated machine tool users, and this has been a continuing feature of that industry. Significantly, Fransman's comparison of the Japanese and Taiwanese machine tool industries found that while in Taiwan the products of competing firms were the most important source of design improvements, in Japan, users, in both domestic and foreign markets, were considered to be more important (1986c: 1386). Small parts of the machine tool industry have entered new product areas in response to domestic demand. For example, Taiwan has a large EDM industry which, like Korea's, supplies machinery to plastics and mould producers. This industry does receive a small amount of feedback from its domestic users but, in comparison to Korea or Japan, there is a general absence of technological inter-firm links. This is caused by the peculiar industrial structure of Taiwan. Large and technically sophisticated machine tool users, which in other countries have traditionally tended to collaborate with producers, do not do so in Taiwan. The indigenous vehicle industry is small, divided between many producers, and, unlike Korea, its production is almost entirely for the domestic market. The defence industry is separated from the civilian machine tool industry which neither sells to the military nor benefits from technology transfer. Finally, the

electronics industry, which promoted the development of high-precision machines in Japan and initiated the development of laser machines in Korea, is in Taiwan primarily assembly-orientated and has no technical links with domestic machinery manufacturers. Such links cannot be substituted by users in export markets. Here distance and communication difficulties make it impossible for producers to react to specific machinery requests. Consequently, Taiwanese producers can only alter their product-mix and designs in response to general changes on the market.

This lack of technological inter-firm links has meant that few skills in the design of special purpose machinery, the custom design of existing products, the production of lines of machinery, or the automation of production machinery have been gained by the Taiwanese industry. And when these capabilities were built up, they could not be applied in any outside industry since there was insufficient local demand for them. While the lack of these links has not hindered Taiwanese firms in their acquisition of new technologies and their ability to follow technological trends on the world market, it is unlikely that the industry will ever become a technology leader without radical changes in its domestic circumstances.

7.3.5 Components and Controls Production in Taiwan

Amsden (1977: 227) also pointed to early difficulties in the technical development of Taiwanese firms arising from the poorly developed state of component and sub-contractor networks. During the 1970s and early 1980s, an extensive network of sub-contractors was created and the indigenous production of several components commenced. Two machine tool firms integrated backwards into the production of ball screws, supplying other firms within the industry. MIRL also became a supplier to the industry, with its heat treatment plant and its gear production. Thus, the Taiwanese industry is now much better supported domestically in its requirements for complex mechanical components. Servo-motor production, under licence from Fanuc, commenced in 1985.

However, several producers suggested that these motors would be no cheaper than those bought directly from Fanuc, and said that they were still ordering from Fanuc. As in Korea, Taiwanese CNC producers mainly use Fanuc controls on CNC machines produced for the domestic market, and exported machines have been fitted almost exclusively with Fanuc controls. Fanuc have a sales office in Taipei, which also operates a repair and maintenance service for Taiwanese firms.⁴⁰ And, as in Korea, Fanuc trained most of the Taiwanese CNC producers in interfacing skills.

However, in contrast to Korea, the Taiwanese effort at designing and producing control units developed earlier and has been undertaken by different agencies. In the early 1980s, several Taiwanese electronics firms commenced control unit production, independently of a similar earlier effort by MIRL. Neither endeavour has, however, proved viable. MIRL initially undertook work on control units in the mid-1970s by entering a servicing agreement with the American controls producer, General Electric (GE). Under this agreement several engineers from MIRL were trained in the US in the repair and maintenance of GE's control units. The agreement did not operate for very long, since MIRL found that GE was not willing to give them the required back-up and support. An interviewee at MIRL suggested that GE was not as prepared to invest in servicing and training in Taiwan as was the independent branch of Fanuc, and, consequently, GE lost its share of that market. Following this venture, MIRL researchers developed units to control milling and boring machines, basic lathes, and grinding machines. Most of the units manufactured by MIRL are used for training purposes, since they are relatively unreliable. A few are, however, sold on the domestic market and one machine tool producer had approached MIRL with an interest in manufacturing them for its own machines.

In fieldwork undertaken by Fransman in 1983, it was reported that there were five firms in Taiwan manufacturing machine tool control units (1986c: 1384-85). He noted that of these five firms, four specialised only in the production of control units, while the fifth also manufactured calculators, cash registers, and microcomputers. At the Ninth Taiwan Machine Tool Show in 1983, 27% of the CNC control units utilised were of

Taiwanese origin. The quality of these controls was far below those supplied by Fanuc, and, as these controls had not been produced in sufficient numbers, their reliability was unknown. These controls were only fitted to machines supplied to the domestic market, since producers did not have the resources to offer after-sales and service facilities to foreign buyers.

When Taiwanese fieldwork for the present study was undertaken in 1985, only two of these five firms were still operating in the controls sector. However, neither of them was making controls for general purpose machine tools. One firm had found a very small niche market in Taiwan, making custom controls which could be retro-fitted to special purpose machine tools, and the other firm had become an agent for Mitsubishi. A third firm, the only Taiwanese machine tool company which is part of a conglomerate, was then considering entering the production of control units. An associated division of the group had commenced making Fanuc's servo-motors and the two divisions had entered negotiations with Fanuc to manufacture control units. Fanuc had offered them some rights to produce control units for milling machines and lathes from its "6" series, a fairly old range of control units. However, they would not enter this agreement since they wanted to make controls from Fanuc's more advanced "10" series.

Taiwan's controls market has changed radically with the entrance of Mitsubishi, which increased competition in a market previously dominated by Fanuc. This was further augmented by a West German controls producer, Haidenheim, which also entered the Taiwanese market in the mid-1980s. Many machine tool producers and personnel at both MIRL and ITRI said that the price of control units sold by the major Japanese companies had already been reduced and they anticipated further reductions. Against this sort of competition, and without the back-up of either a large internal market or a larger company prepared to support their production, the small domestic producers could not survive.

It should be stressed that two Korean firms (B and C) which have experimented with control unit production are very different from the

Taiwanese controls producers in two respects: they are both machine tool producers, and they are both part of conglomerates. In the case of Firm B, there are considerable interests in microelectronics production in another division of the *chaebol*, which could in future provide important technological support for the development and production of control units. These differences mean that the Korean firms, unlike their Taiwanese counterparts, are not economically dependent on selling control units. Furthermore, in both Korean cases the firms were intending to produce controls only for use on their own internal market. Should these firms decide to export their control units, they would also enjoy an advantage over Taiwanese producers, since both have already established their own sales outlets in the US through which repairs and maintenance services could be organised.

Developments in the Taiwanese control unit market may offer certain encouragement for Korean CNC producers. Enhanced competition in Taiwan's market may ultimately develop in Korea's. It is unlikely that Mitsubishi and Haidenheim entered the Taiwanese market because of increased domestic activity in this sector. Rather, it is highly probable that the main factor influencing these firms was the expansion of Taiwanese CNC exports to the US and Europe. Controls producers wanting to increase their global market share must get their controls onto the machines which are sold to industrialised countries and Taiwan's industry was targetted because of its obvious importance in such markets. And, while Korea's CNC industry is still far more orientated to its domestic market than Taiwan's, there is clear evidence of a shift. On the one hand, increasing CNC exports from Korea are beginning to attract other controls producers, while, on the other, Korean firms, dissatisfied with the high price of Fanuc controls, have actively sought out alternative suppliers. It is plausible that price reductions in controls in Korea will occur because of increased competition on its market between international suppliers, and not because of the commencement of domestic production.⁴¹

7.4 Conclusions: What Model for NICs?

Generally speaking, the Taiwanese machine tool industry displays an arguably successful development pattern in strong contrast to that adopted by Korea. Taiwan's CNC industry was, and continues to be, a highly export-orientated enterprise, producing standardised, basic, low-cost machines for sale to industrialised countries. The Taiwanese economy lacks a strongly developing machine-using sector into which the indigenous machine tool industry could sell sophisticated goods and with which it could collaborate in innovatory processes. Similarly, it might plausibly be said that the Japanese machine tool industry has provided Korea with not only an abstract pattern but, crucially, a model it has actually followed and an important constraint on its future development. Japan in the past, like Korea at present, initially concentrated on supplying and supporting its domestic machine-using industries which were themselves in a position to demand more sophisticated tools appropriate for mass production. Only when, through supplying its domestic users, Japan had reached a position of high productivity and cost competitiveness did it then systematically enter the world market, with the remarkable effects that now constitute a major obstacle to Korea wholly imitating the Japanese career.

More specific comparisons between the three national machine tool industries have been made throughout this chapter and need not be repeated here. Indeed, a more general question arises as a result of these comparisons. Were the government of a hypothetical NIC now to be considering establishing or re-orientating a CNC industry, which, if any, of these models should it follow and on what terms? What features of its own economy should it bear in mind in making such decisions?

The first consideration in any decision must be political as well as economic: what development objectives does the country envisage for its economy and which of these can be sustained by its resources? While Japan and the US represent exemplars of what it is to be a fully developed industrial economy, there is no point in equating "success" solely with the effective imitation of those patterns. In Japan, for

example, the machine tool industry performs a valuable support function for its machine-using sector. In Taiwan, it does not. Nevertheless, because of its high levels of exports, it is entirely proper to describe the Taiwanese machine tool industry as a success. And, as such, it represents an entirely plausible pattern for an LDC or a NIC to follow.

NICs contemplating the institution or re-orientation of a machine tool industry might be well advised first to analyse the constitution and potential of their domestic markets, including the military sectors. Are such markets in a position to absorb a given quantity and quality of machine tool output? If they are not, then the promotion of a domestic machine tool industry must mainly be justified by its potential significance as an employer and foreign exchange earner. Small industrial economies, such as Hong Kong and Singapore, are prime examples of industrial environments which would not benefit significantly from the existence of an active machine-building sector, and in which such a sector will only survive if the industry has a competitive advantage over producers in other countries.⁴² If the NIC is in this position, then there is little reason why the machine tool industry should be picked out by government for special promotion and protection, but the industry might be included in general measures used to encourage all industrial sectors. However, if there are particular security considerations which seem to require an indigenous machine-building capability, governments may consider it desirable to intervene more directly.

Alternatively, if analysis of the domestic market identifies significant potential to absorb quantities of machines, especially of more complex or special purpose types, then a different strategy may be indicated. In these cases, governments may consider it beneficial to nurture the industry by selectively protecting the domestic market and actively encouraging firms to invest in this sector. There should, however, be caution in such an approach: total import substitution, as the Indian example demonstrates, can lead to highly inefficient industries, which ultimately put their domestic users at a disadvantage (Lall, 1987: 227-28). Promotion of the industry should take into account the interaction of the machinery sector with other parts of industry and how

such interaction might be initiated and positively managed. No doubt, the benefits of the support functions performed by a machine tool industry are difficult to quantify.⁴³ However, they are qualitatively easy to establish; they are widely recognised by machine tool users; and, as a number of analysts have convincingly argued, such benefits count as the major justification for the encouragement of the machine tool industry in industrialising countries (Datta Mitra, 1979; Rosenberg, 1976: 99-100).

Notes

1. See, for example, Foster-Carter (1988), Enos and Park (1988), Petri (1988), and Harris (1986).
2. For example, the growth in Korea's textile exports occurred when Japan was reducing its textile industry. Korea's entry into heavy and chemical industries in the 1970s coincided with Japan's move away from polluting industries. In shipbuilding, when Japan rationalised its industry in the early and mid-1970s, Korea rapidly expanded with very high investment, and, with the advantage of lower wage rates than other industrialised countries and low steel prices, was able quickly to gain a significant share of the world market. All these industries had a high labour content, and Japan's competitiveness had declined as labour rates had risen.
3. Manufacturing activities in the Korean industries that had existed during World War II rapidly declined following Korea's partition in 1945. Japan, which had been Korea's major export market before and during the War (consuming 99% of exports in 1944), virtually ceased importing goods from Korea. Resources to maintain and repair manufacturing facilities created, but also severely worn out, during Japan's war effort were no longer available. In addition, the Koreans had difficulties obtaining supplies of raw materials. The ownership of most industries was, as enemy property, transferred to the US military government, which knew nothing about the economy and little about the country's industrial structure. The US military could not efficiently operate Korean manufacturing facilities; frequently, unqualified US military personnel were left to manage industrial plant. Much of the existing manufacturing plant, and several of Korea's mines, were cannibalised and allowed to decay to such an extent that they were inoperable and could not be rescued. By 1947, industrial employment decreased to about 60% of its pre-division level, and, by the end of 1948, it is estimated that industrial output was about 10-15% of its capacity at division (Henderson, 1968: 136-38).
4. In Japan, the Temporary Measures for the Development of the Machinery Industry Law (1956) aided the modernisation of a selected 21 industries, including the machine tool industry. Through this act, MITI provided long-term and low-cost government loans, through the Japan Development Bank, for investment in new equipment: special interest rates of 6.5% were given on these loans, while the standard rate at the time was 9%. The machine tool industry was a main beneficiary of this aid, receiving 20% of the loans allocated under this programme between 1957 and 1961 (Chokki, 1986: 131-46).
5. A KOSAMI spokesman did suggest that for many of the new machinery producers, which were still in an infant industry stage, increased competition on the domestic market would make survival difficult.
6. In Watanabe's survey of the Japanese CNC machine tool industry he noted that "[m]ost firms felt that competition was 'extremely intense' at home and abroad" (1983: 45).

7. MITI has run several large scale projects which have supported the Japanese machine tool industry's development of NC and CNC machine tools. In 1957, MITI's Mechanical Engineering Laboratory commenced a three-year project on the "Automatization of Machine Tool Operation". Between 1973 and 1981, it was engaged in a project to design a model of an unmanned, automatic factory for manufacturing machinery. In 1977, a high-profile project was initiated to develop an FMS utilising lasers (Metalworking, July 1987: 20). In the 1980s, MITI's research and development projects have been concerned with the development of new machining technologies for cutting and shaping new materials, including ceramics.
8. The example of the vehicle industry is cited in Chokki (1986: 142), and the steel industry in Lynn (1985: 260).
9. Indeed, it has been suggested that the international and competitive success of the Japanese machine tool industry is "in part, a result of more than 20 years of [Japanese] government intervention in the machine tool industry". It must, however, be uncertain how the industry would have developed without government support and promotion (quotation from an International Trade Commission Study, cited in DiFilippo (1986: 115)).
10. See Enos and Park (1988) for the Korean case and Peck and Tamura (1976) for the Japanese situation.
11. The vehicle industry is the largest single machine tool consumer in Japan, in the early 1980s absorbing approximately a quarter of Japan's total machine tool production (Japanese Machine Tool '85/85 Guide, 1985: 14).
12. See Abegglen and Stalk (1985: 54-66) for a comprehensive analysis of this entry method.
13. For a description of the development of NC machine tools by the Japanese machine tool industry, see Metalworking, Nov. 1982 and July, 1987 (Special editions on machine tool history and NC development respectively); Watanabe, 1983: 32-35; Chokki, 1986; and Vogel, 1985: Ch. 3.
14. Westphal et al. (1984: 296) note that the contribution of direct foreign investments to gross investment in these years was approximately 8%.
15. Enos and Park (1988: 38) show that the number of technology contracts approved by the Korean government steadily increased through the early 1980s. In one particular sector, factory automation technologies, Kim Linsu (1987) shows that in 1985 and 1986 compared to previous years a large number of licensing and direct foreign investments were made in the field of programmable automation technologies.
16. This close relationship was described in Chapter 4. For a detailed analysis of the evolution of this relationship and its effects on

the technological development of the machine tool, see Watanabe (1983).

17. Of course, more recently the differential between Japanese and US labour costs has shifted dramatically, even enabling the economic re-importation into Japan of cars produced by US subsidiaries. In general, American and European plants are far more vertically integrated than Japanese plants. In GM's vehicle production, purchases account for 50% of the value of sales, but for Toyota this figure is 80% (Abernathy et al., 1981). The Japanese plants rely on a vast number of small sub-contractors to manufacture parts for them and it is not unusual for the main producer to have an equity interest in these firms or to stipulate the machinery and methods used for production.
18. See Sciberras and Payne (1985: 151-52) for an analysis of potential problems in following this strategy. See also Garnett (1987b) for a description of Japan's expansion and developments of more specialist machinery and its extension into industrialised country markets, including the supply of car-building machine technology.
19. For example, Korea's sales of DRAM chips have increased dramatically following limits on the sale of Japanese memory chips in the US (Electronics, 28 April 1988: 21).
20. The other countries warned were Britain, Spain, Italy, Sweden, Brazil, and Singapore. For details of the restraint agreements, see Wall Street Journal, 17 Dec. 1986: 4, and Metalworking, May 1987: 20-23.
21. For example, US insurance firms have been able to set up joint-venture companies in Korea. Sales of US cigarettes have been permitted on the domestic market which was previously a total government monopoly. US cigarettes are, however, sold through the government monopoly at a high price compared to indigenous brands. Tariffs on imports of US wine have been reduced and imports of some other agricultural products have been liberalised (Ford, 1988).
22. For a description of the application of "Japanese manufacturing methods" in industrialised countries, see, for example, Abernathy et al. (1983).
23. See Nolan (1986: 19-45) for a detailed account of the influence of the US on the development of indigenous defence industries in Korea and Taiwan.
24. Per capita GNPs for 1985 given in EIU, 1987a, 1987c.
25. Between 1975 and 1985, manufacturing wages rose over three and a half times; during the same period, consumer prices less than doubled and wholesale prices rose by 50% (EIU, 1987c: 15).
26. All ranks in global industry have been formulated on the value of machine tools manufactured as given in the "World Machine Tool Production and Trade" data in American Machinist, Feb. 1986: 87-92.

In 1985, the contribution to Korea's GDP from manufacturing amounted to US\$25 billion (EIU, 1987a: 12). Taiwan's figure was similar at approximately US\$24 billion. (This statistic has been extrapolated from the 1986 and 1985 figures for Taiwan's GDP, and the 1986 figure for the contribution of manufacturing to GDP, assuming that this element of GDP did not change radically between these two years (EIU, 1987c: 12-13).

27. This structure of Taiwanese machine tool firms seems unlikely to change. Fransman notes that Taiwanese firms are unwilling to merge or join larger groups, preferring to follow the Chinese proverb "Better the head of a chicken than the tail of a cow" (1986a: 206).
28. In 1969 and 1970, imported machine tools accounted for over 60%, by value, of machine tools consumed on the domestic market (Jacobsson, 1986: 148).
29. One Taiwanese interviewee suggested that many of the machine tool exports to Vietnam at this time were fictitious, their putative purchase being used by the overseas Chinese in South Vietnam as a way of getting money out of the country.
30. Surprisingly, Jacobsson (1986: 148) does not include the production or trade statistics for 1982 in his time series data, although he included the figures for 1983, and does not comment on the causes of depressed machine tool production in Taiwan in 1982 and 1983.
31. In 1984, the US imported machine tools valued at US\$1,356 million, of which Japan contributed US\$683 million (50%), West Germany US\$205 million (15%), and Taiwan US\$99 million (7%) (NMTBA, 1986: 128).
32. It should be noted that there is still a significant market in Europe and the US for small standardised machine tools (both conventional and CNC) which are used by small workshops and repair shops.
33. See Metalworking, July 1985: 13 and Nov. 1986: 152-57, for a more thorough survey of the problems in the industry at this time.
34. Calculated from figures in Tables 7.2 and 7.3. 1985 figures are taken from American Machinist, Feb. 1986: 90.
35. The extremely low value of CNC milling machines may be explained by the fact that many of these machines are manufactured on an OEM basis and are actually exported without their electronics or control unit. These are later fitted in the country of destination. The reason for this practice is that the Taiwanese producer has to pay a tariff on the import of these items, and, although this is repaid on re-export, the time delay in repayment creates an extra cost for the producer. In total, over a third of all CNC machines manufactured in Taiwan in 1984 were not fitted with control units (data supplied by ITRI, Taipei).

36. For example, the conglomerate producer has collaborated with another firm in the group in the installation of transfer lines.
37. For background on these measures, see Jacobsson (1986: 163-68) and Fransman (1986c: 1387-88).
38. This was also a general finding of Amsden (1985), Jacobsson (1986), and Fransman (1986c).
39. The firm could have possibly exported its lathe with robotic arm attachment, but this would have considerably increased the work of its branch offices. Furthermore, the main markets for Taiwanese machine tools in the US were fairly small job shops, which, like Taiwanese domestic users, were not at that time installing such automated equipment.
40. This office is a branch of Fanuc's overseas affiliated company in Singapore. Fanuc may have established the company in this way so as not to have direct links with Taiwan and, therefore, jeopardise its licensing and production agreements with mainland China.
41. With a general increase in the number of machine tool producers commencing production of their own control units, and increasing competition between existing controls producers, there is a high probability that controls prices may be reduced globally.
42. As shown in Chapter 4, the Hong Kong machinery industry, which evolved in the early 1980s, subsequently declined because it could not compete with very cheap imports from China.
43. Jacobsson concludes that, compared to Taiwan, "Korea has a slightly lower benefit to cost ratio on account of the implementation of general trade restrictions" (1986: 238). He bases his analysis of the benefits and costs of fostering the machine tool industry in Argentina, Korea and Taiwan on measures of the performance of the respective industries derived from the size of their output, their export performance, and their ability to adjust to the manufacture of CNC lathes. Against this he calculates the direct financial costs of promoting the industry (1986: 201-09). He does not, however, consider that Korea's machine tool industry is radically different in orientation and product range, and that the major benefits deriving from this industry for Korea originate in its ability to support the machine-using sector.

CHAPTER EIGHT

Conclusions

This thesis has focused on a particular industry at a specific period and in one country. The experiences of other industries and other countries have been drawn upon mainly to flesh out an understanding of the career of the CNC machine tool industry in Korea. Nevertheless, if it is indeed a "case study", then this analysis ought to have relevance for a series of more general concerns. Firstly, it ought to be visible as methodology. While the problems this thesis has addressed have usually been the province of development economists, the approach taken here differs in certain respects from those that typify economists' analyses. What special contribution can an analyst with a predominantly engineering background and orientation make to the study of technology transfer and the acquisition of technological capabilities? Secondly, the thesis has intermittently argued that the machine tool industry, while tiny in terms of the value of its own output and significance in world trade, has an absolutely central role in any machine-using economy. What, precisely, is that role? What functions does the machine tool industry perform within an industrialising economy? Should countries endeavouring to industrialise support an indigenous machine tool industry, and, if so, for what reasons and on what terms vis-à-vis the availability of machine tools on the world market? Thirdly, the history of the machine tool industry has been intertwined with both civilian and military clienteles for its goods. It appears that in both Japan and Korea the influence of the military has been relatively limited compared to the situation in countries such as the US and the UK, and, conversely, that the influence of links between indigenous machine tool makers and mass-producers of civilian goods such as automobiles has been enormous. What have been the consequences of these contrasting environments for the different national machine tool industries? Are there lessons to be learnt by Western industrialised countries from Korea and Japan? Fourthly, the study of the machine tool industry in Korea (as well as in Japan) has discerned the pervasive role of government policy and government intervention. Governments in these countries have had both the power and the will to take a range of measures to encourage, direct, and discourage the

development of their indigenous industries. To what extent, if at all, can such governmental policies be replicated in Western countries, or, for that matter, in other developing countries? Finally, as the thesis title indicates, the overarching concern of this study has been with the acquisition of technological capabilities. The acquisition of requisite skills in the Korean CNC machine tool industry has been taken as a special case of a process necessarily implicated in the industrialising process. How do countries at the outset of industrialisation go about building up the capabilities they require? What is the relationship between the nature of the technology and the ease or difficulty with which the relevant capabilities are acquired? What learning methods can be used? Which are likely, in given circumstances, to be the most effective? And, importantly, what attitude towards learning is most likely to make the use of any learning method most productive? What relations are there between the organisational and business structures within which production takes place and the facility of learning? The concluding sections summarise, refine and develop materials in this study which engage with these, and related, questions.

8.1 An "Engineer's Approach"

This thesis is different from many studies of technology transfer in one significant respect: it devotes much attention to the specific nature of the technologies concerned and strives to show some analytic benefits of doing so.¹ In this respect, it might fairly be said to display an "engineer's approach" to understanding technology transfer and the acquisition of technological capabilities, processes which have traditionally been the preserve of economists and students of politics. It is arguably a general feature of academic analysis that the domain in which the analyst has expertise is regarded as problematic while other domains are taken as given. Thus, the valuable work of development economists in these areas has tended to see the acquisition of technological capabilities in terms of "relative factor prices", "comparative advantages", and the like, while implicitly treating radically

varying technologies as essentially similar. Yet there are analytic prices to be paid for "black-boxing" technology in this way.

As a general matter, technology ought to be viewed as a problematic variable because technologies differ in their application in different environments and because they change over time. For these reasons alone, technology cannot be regarded as a constant between settings or in a specific setting over time. More specifically, technology ought not to be conceived as a discrete product which may be bought and utilised with equal ease in every country, whatever that country's stage of development. One should not black-box technology because the nature of the technology is a major factor in the industrialising process, a factor which varies from technology to technology, and which interacts with other variables influencing the process.

Thus, the case study materials show that different aspects of CNC machine tool technology made different capability demands upon Korean industry and infrastructure. Interfacing and assembly capabilities were relatively easy to acquire, since they called upon knowledge and skills which were already present in Korean industry or for which foreign assistance was readily available. By contrast, the technological demands of complex CNC design and almost all aspects of control unit production still have not been met by the Korean industry. The complexity of the technologies concerned presents a major obstacle to Korea, given its existing pool of capabilities. Moreover, the case study indicates that this sort of orientation allows an understanding of which transfer processes are likely to be most effective, given the demands of the technology and the reservoir of capabilities which exists in a setting. Nevertheless, it would be wrong to claim too much for the "engineer's approach" to technology transfer. The capability demands made by specific technologies are worth analysts' attention, and they are important considerations in themselves, but they are by no means wholly independent variables. Economic environments and political decisions can importantly lower or raise the barriers to entry posed by technological complexity.

8.2 The Machine Tool Industry as Part of an Industrial Structure

This thesis has repeatedly pointed to and stressed the central and strategic place of the machine tool industry in a machine-using economy. The relationship between machine tool users and producers is symbiotic—the users supplying the initial skills to establish a machinery industry and continuing to demand of it new types of machines, the producers contributing to the overall productivity of users and supporting their product developments. Such technological guidance cannot be offered to users by any other industry, and it can be offered only with great difficulty by a machinery industry in another country. It is because of these externalities that the machine tool industry is often given infant industry status, and, indeed, special measures were introduced to promote its formation in both Korea and Japan. For all that, Little (1982: 240-59) has been sceptical of these arguments and has suggested that such benefits from an indigenous machine tool industry may either never occur or may take an unsatisfactorily long time to be realised. Yet the findings of this thesis count as evidence against Little's scepticism. The Korean machine tool industry is already beginning to contribute to the productivity of local user industries and to new technological developments, even though a full range of technological capabilities has not yet emerged in the industry. Even a partially developed machine tool industry can perform valuable support functions for its local user industries.

The Japanese case is perhaps the best illustration of close technological links between machine tool producers and civilian users. However, there is no necessity about such links between an emerging modern national machine tool industry and domestic user industries. Indeed, Taiwan offers an example of a successful export-orientated machine tool industry which has not evolved close links with national users. At the same time, the Taiwanese experience shows that an industry which develops in this manner only acquires a narrow range of capabilities and can therefore offer only limited support to the machine-using economy. The Taiwanese manufacturing sector remains highly dependent upon imported machinery and foreign sources of expertise. And

the national machine tool industry seems set on a course which will keep it a technology-follower instead of a technology-leader, with clear consequences for its own long-term profitability.

An important difference between the Korean machine tool industry and many other sectors of Korean manufacturing industry is its orientation towards the domestic as opposed to the export market. It is important to note that this orientation is not necessarily, as Jacobsson suggests, an indication of weakness in the industry. Several producers are, indeed, active exporters, but in an industrial climate where home demand is expanding it is not surprising that they focus on supplying the domestic market. Even though such machine tool firms are not direct exporters, they perform a critical task by directly enhancing the competitiveness of other Korean manufactured exports. In this orientation, the Korean machine tool industry is very similar to Japan's, as it was in the 1960s and early 1970s.

Trade is, however, an important aspect of the global machine tool industry, each country specialising in particular sectors, and user countries importing machinery unavailable domestically. But specialisation does not immediately appear with the promotion of a machine tool industry; it takes many years to evolve and is dependent on the demands of its users. Japan took at least 25 years to fully acquire machine tool capabilities and to find a specialist sector of production in which it could effectively compete on the world market. Similarly, Taiwan has now also found a specialist area - low-cost, moderate-quality machine tools - and has been able to exploit its concentration in this sector. The Korean industry is not as yet focused enough to benefit from such specialisation.

The importance and benefits of inter-firm linkages for both technology acquisition and for innovation are not, of course, limited to machine tool producers and users. Indeed, such mechanisms have been identified in other industrial sectors. For example, Von Hippel has recently pointed to the advantages of close links and geographical proximity between semiconductor equipment manufacturing firms,

semiconductor producers and users, a situation which once advantaged US producers and currently obtains in Japan. He suggests that when such a system operates efficiently many different manufacturers within the system benefit significantly.² And the absence of such close liaisons does not just remove such benefits but places all producers at a distinct disadvantage (Von Hippel, 1988: 121). Thus, an adequate understanding of the development of any industry and the conditions for innovation within it requires an examination of the industrial structure in which it operates.

8.3 Clienteles and Consequences

Chapter 4 noted the work of Melman (1983a, 1983b) and DiFillipo (1986) on the relations between the US machine tool industry and the military. While military patronage has, indeed, been influential on technological progress in the machine tool industry (as witnessed by the decisive role of the US military in the original development of numerical control), these writers document the long-term damaging effects on the American industry of concentration upon production for specialised defence requirements. Why have such links had negative consequences for the machine tool industry when it is so generally agreed that close links with such consumers as the civilian manufacturing sector have been beneficial? What lessons are there to be learnt from the US experience by emerging machine tool industries in countries such as Korea?

The problem with production for the military is four-fold. Firstly, the market for the specialised machine tools demanded by the modern military is extremely limited. Firms which make machine tools for military requirements find that they cannot sell them to any other client, even if security considerations allow them to do so (which they often do not). Secondly, once producers orientate themselves to specialised military needs they are usually unable to effectively supply the larger market for general purpose machine tools constituted by the civilian manufacturing sector. Such producers, therefore, become more vulnerable to an exaggerated form of the demand cycles which afflict the machine

tool industry in general, as they cannot easily shift from supplying the military to either civilian or export markets. Thirdly, the cost environment for military producers is substantially different from that affecting machine tool firms catering for the general manufacturing industry. In this respect, the machine tool industry is little different from other industries selling primarily to the military. Cost-plus contracts, to take one example, do not encourage the cost discipline required for mass-production for the civilian sector, and, especially, for the export market. Finally, a national machine tool industry which is highly orientated towards production for the military can only with difficulty fulfil a role of supporting the local civilian machine-using economy. For all that, it must be noted that military patronage may have a number of positive effects on machine tool firms. Civilian machine tool producers may be able to benefit from either economies of scope or scale from supplying the more standardised requirements of the defence sector. In addition, military demand may serve an important role in stimulating technological innovation, though whether, when and at what expense local industries benefit from that stimulation is problematic.

The experience of Japan tends to reinforce Melman's and DiFilippo's arguments. Many analysts agree that the lack of a significant military orientation in the Japanese machine tool industry has not hampered its development and probably has positively aided it. Thus, Japan's machine tool industry has not become a specialist in the manufacture of machinery which may only be used by one specific user, but has developed machinery which can be utilised in many different production situations. In fact, the Japanese industry has been characterised by its very close links with civilian mass-producing industries, and, in particular, with the vehicle industry. The requirements of this industry have disciplined the Japanese machine tool industry to design and make machines which can be used by mass producers, in which the main production requirement is cost effectiveness and repeatability rather than precision. From this base, the Japanese industry has been able to expand by supplying other users and producers in different markets, with the spectacular results noted in Chapters 4 and 7.

Moreover, the Japanese machine tool industry has used this base to expand into the manufacture of more complex and special purpose machinery. It is important to note that the reverse path does not appear to be as easy to travel. The machine tool industries of the US and Europe which entered specialised niche markets following the expansion of Japan's general purpose exports have not been able regain any of their share in the more general market. Indeed, these producers are now facing increased competition in their niches from Japanese producers.

It would seem, therefore, that the examples of the US and Japan provide an important lesson for Korea in considering its future development. Although Korea's heavy and chemical industries, including its machine tool industry, were in fact particularly promoted in the mid-1970s in order to support the military, there is little specialised production for this sector. And where such production does occur in the Korean machine tool industry, the machines produced can often be used in the civilian sector. In fact, since the early 1980s the emphasis of Korean machine tool output has strongly moved away from a defence orientation towards one more similar to that of the Japanese industry, with increasingly close links between machine tool firms and vehicle producers. The future for Korea is extremely difficult to predict. If government policy alters— as it might well do in light of changed security considerations— the focus of Korean machine tool production could shift accordingly. Nevertheless, there is some evidence that Korean policy-makers are well aware of the Japanese and US experiences, and, in particular, of the risks that such specialisation would pose to a small and sensitive product area and, by extension, to Korea's general technological and economic development. To some extent, Korea's own experience of problems resulting from over-expansion in the heavy industries has reinforced this lesson.

In this connection, it is interesting to note that the Taiwanese industry has gone to the other extreme from the US. While its civilian industries are very efficient and its machine tool industry even supplies some defence contractors in other countries, Taiwan's military is totally closed to its civilian machine tool industry and is highly inefficient in

producing for its own requirements. Thus, Taiwan's civilian machine tool industry is unable to secure some economies of scale or scope that could be gained from producing for the military. Accordingly, there is a case for taking steps to ensure that the two parts of the market for the machine tool industry— civilian and military— are both catered for, since there can be technical exchanges as well as market advantages arising from a balanced orientation. The danger seems to stem from situations in which military requirements become predominant, driving a national machine tool industry up a cul-de-sac from which there is no easy escape.

8.4 Government Intervention

Many analysts have pointed ^{to} the importance and pervasive role of government intervention in Korean industrialisation. Particular government policies designed to promote and direct the machine tool industry have been repeatedly noted in this thesis, although it is probable that some form of such an industry would have developed in Korea without intervention from above. Of course, an active and interventionist government is by no means unique to Korean industrialisation: a broadly similar pattern has been widely noted by analysts of Japanese industry.³

It is not necessary here to summarise the precise thinking and direction behind relevant government policies vis-à-vis the machine tool industry. Nor would it be correct to assume that government intervention in Korean industry has invariably produced results that government itself has regarded as beneficial— as witnessed, for example, by the results of government's promotion of the heavy industries in the mid-1970s. Rather, it is important to stress four general aspects of Korean government policies in relation to industrial development as a whole and in relation to the machine tool industry in particular. Firstly, since the early 1960s Korean governments have understood it as their role to take a long view of national development, both economic and social. Following policies laid down in a series of five-year plans, the government has intervened in such a way as to encourage the realisation of relatively

long-term industrial development goals. It has been able and willing on occasions to sacrifice short-term commercial demands for immediate profitability in exchange for long-term benefits, and it has aimed at the creation of an industrialised economy able to support its own capital goods requirements, to enter export markets in a fully prepared position, and ultimately to become not just a technology-follower but a technology-leader.⁴ The Korean government has invested heavily in the establishment of technical institutes to support industry and to promote new technological developments, and, although the machine tool industry currently receives little support from such institutes, they were an important resource at an earlier stage of development. Nor has the government felt obliged to over-rush such developments or to adopt short-term expedients such as wholesale import bars in order to encourage domestic industry. In addition, the Korean government was able to take an overall view of development and to implement an integrated approach, as was manifested, for example, in the 1970s when government encouraged the expansion of the national industrial base, in order to reduce dependence on the manufacture of light export goods and to enable support of the defence industries.

Secondly, government has worked in concert with non-governmental organisations also able to take a relatively long-term view. Although government promotion of the *chaebol*, especially in the machine tool sector, was criticised and modified accordingly (as noted in Chapter 5), it was in the conglomerates that government found partners similarly able to take a long view and to adopt the measures which government analysts felt were most likely to yield success. The Korean government was actively concerned to encourage the assimilation of technology and found in the *chaebol* organisations that were generally able to do so effectively. Indeed, some of the *chaebol* have developed their own research facilities, effectively taking over parts of the support function initially performed for the machine tool industry by government institutes. Smaller independent firms in the main lacked the *chaebol*'s proven record in acquiring technological capabilities and implementing them in production, but, where such firms had given evidence of their

technical ability, government was quite willing to give them extensive support.

Thirdly, government interventions in the machine tool industry in particular and in the industrialisation process in general have manifested a high degree of selectivity, being continually adjusted and amended in light of experience from prior planning efforts and from changing market conditions. For example, Korea has now recovered from the unwise investment decisions of the mid-1970s and has reduced the military emphasis of its earlier policies. Government has been both active and selective in its role in negotiating the terms of large technology importation projects. Indeed, Enos and Park's major conclusion (1988: 248) was that the success of technology absorption in these projects was largely due to the terms stipulated by government in such agreements, maximising the transfer of technological capabilities. Perhaps the best instance of government's selectivity and policy eclecticism was its use of trade restrictions. Although such analysts as Datta Mitra (1979: 32), Lall (1987: 240) and Jacobsson (1984: 290) have criticised aspects of the protection of the domestic market for the purpose of promoting indigenous industries, the Korean government's use of a range of protective measures (like Japan's) has proved highly selective and apparently productive in the machine tool industry. Only sectors which could be reasonably expected to catch up fairly quickly or to manufacture goods of an adequate standard were accorded blanket protection from imports. Moreover, special efforts were made to ensure that users, and especially exporters, were not disadvantaged by protection. Korea has also been aware of its vulnerability to import restrictions imposed by its major trading partners and has adjusted its trading and manufacturing policies to take this into account.

Finally, government has taken a particular view of the connection between the machine tool industry and the machine-using economy as a whole, and it has directed its policies primarily towards the realisation of this connection. While the Korean government's initial promotion of the heavy and machinery industries in the mid-1970s was largely informed by military concerns, emphasis soon shifted towards the promotion of

industries with high linkage effects. In the late 1970s and early 1980s—the period in which the domestic CNC industry was taking shape—the Korean government was seeking to encourage those industries which would support the overall thrust of development of the civilian manufacturing sector. Indeed, it was largely for this reason that the machine tool industry was the recipient of significant government promotion. Furthermore, government identification of the central support function that could be performed by the machine tool industry was broadly shared by some *chaebols*. They too sought to build up important machine tool production within the conglomerate structure, for the specific purpose of supporting their machine-using manufacturing activities. These policies are already producing results: the sorts of links between machine tool makers and vehicle manufacturers that characterise Japanese industry have begun to develop in a very significant way in the Korean context.

8.5 Acquiring Technological Capabilities

Two important features of the process of acquiring technological capabilities need to be emphasised here. Firstly, capabilities take a long time to acquire and build upon. Accordingly, it would be a mistake on the part of either analysts or governmental and industrial planners to expect industries to mature within a few years. Learning is typically neither a straightforward nor a quick process, and, if planners really intend to build up a mature industrial economy, they must be prepared to take a long view. Secondly, although a range of learning methods can be, and have been, used to acquire technological capabilities, none of these is guaranteed of success unless there is substantial effort and investment in their implementation.

Although acquiring a complete range of capabilities may be a lengthy process, this does not necessarily mean that the industry in question has to be inefficient for the whole of this period. The acquisition of design skills may be the best sign of an industry that is no longer in the "infant" stage, but, even during the phase in which these skills are still under-developed, a machine tool industry may still be efficient in other

respects and may be in a position to offer support to machine-using industries. Thus, Westphal et al. have shown that by the late 1970s and early 1980s many successful Korean industries had acquired high levels of ability in plant operation, but few in product and plant design (1984b: 291). This pattern, they say, is a natural part of the development process: operating skills are learned before a capability for design can be acquired, i.e., know-how has to be indigenised before know-why is secured. The case study has shown that the Korean CNC machine tool industry has started on this second stage of development and has acquired some, though by no means all, of the skills needed to design complex machine tools. And, as noted, this process is to a marked extent dependent on the complexity of the technology being transferred. Even within the small industrial sector considered here, there was considerable variation in the rate of capability absorption, depending upon a range of technological factors, as well as upon factors distinguishing the capability-base of different firms.

The Korean machine tool industry has not relied upon any single learning method. In its build-up of technological capabilities it has, in fact, used to varying extents practically all the learning mechanisms categorised by analysts such as Lall (especially 1987) and Bell (1984). What appears to be far more important than the specific learning method used is the attitude in which Korean firms have approached the learning process. An important feature of their use of foreign technology appears to have been the fact that many, so to speak, "prepared themselves to learn" before they made any decisive learning investment or commitment. For example, firms prepared to learn by first using CNC machine tools, experimenting with them, and attempting to develop them, before they undertook to manufacture them. When these firms subsequently entered negotiations for licensing agreements, and during the operation of these agreements, they were rapidly able to learn and to improve the quality of their product. Several firms were also able to use these agreements as a base for enhancing their own design capabilities. This finding therefore complements the Korean study of Enos and Park (1988: 233-34). They documented that in several cases of large government-organised technology imports, for example in the steel industry, there was intensive learning

about all the various technical options open to them before they finally entered into a technology agreement. In general, Korean firms, aided and encouraged by government, used licensing agreements in such a way as to maximise the efficiency of capability transfer.

Finally, an aspect of capability acquisition which has received relatively little attention needs particularly to be underlined here. This is not, perhaps, so much a discrete learning method as a mechanism by which almost any form of learning may be most effectively realised. Chapter 2 pointed to a process designated as "interactive learning": technological capabilities might be built up and innovation encouraged when machine tool producers, users and suppliers were in close contact with each other, aware of the other's problems, and in a position efficiently to exchange technical information. Indeed, partly owing to the *chaebol* structure, the Korean machine tool industry is characterised by a high degree of effective interaction between the relevant firms. It is just because of the importance of such interaction to the productivity and efficiency of the machine-using sector that the existence of an indigenous machine tool industry is widely considered important to an industrialising country.

Yet the interaction by which learning occurs has a quite small-scale and pervasive pattern which analysts have not, in the main, noticed. As a practical matter, learning seems to proceed most effectively when people are moved about and not merely machines, blueprints and instructions. Thus, among many examples, Korean firms have actively sought to learn by sending their personnel to foreign plants in order actually to see the technology and technological processes in operation. The Korean government has intermittently provided incentives enabling foreign engineers and designers to come to Korea to transfer their expertise at first hand. And the close proximity of machine tool producers and users on such sites as Changwon, and within the *chaebol* structure, has enabled personnel involved in machine making and machine using to come together and to interact intensively and on a day-to-day basis that would not be possible if they were physically separated.

One analyst of technology transfer in a setting far removed from Korea or the machine tool industry has, in fact, noted the importance of such informal mechanisms. Earlier chapters have briefly alluded to von Hippel's (1987) study of "informal know-how trading" among personnel in US steel minimills. Von Hippel's work deals with firms which are nominally rivals, but even here he notes the importance of networks of exchange between technical personnel, especially as built up and maintained through patterns of face-to-face interaction, at conferences, through on-site visits, and the like. This writer stresses that these kinds of informal mechanisms may be fully general, containing "no inherent restriction as to the nature of the know-how traded or as to the nature of the trading parties". Indeed, von Hippel actually points to research in the sociology of science which he believes makes a strong case for the pervasive operation of informal and tacit mechanisms in the transfer of skills. In particular, he cites the work of H. M. Collins on the transfer of skill in laser building (von Hippel, 1987: 301). Collins (1974, 1985: Ch. 3) develops a general argument that skills cannot be acquired solely through formal and verbal means and that the experience of seeing skills in operation and sharing the "culture" of a skilled person is at some point essential in skill acquisition (cf. also Rosenberg 1976: 154-56). Moreover, there are several other recent studies, e.g., those of Kusterer (1978) and Harper (1987), which similarly emphasise the importance of the tacit dimension of knowledge and skill and the importance of direct interaction in its transfer.

This thesis was not undertaken with the design of contributing to any wholly general debate over learning methods. Nevertheless, the case study of the acquisition of technological capabilities in the Korean CNC machine tool industry strongly supports the views of von Hippel and Collins. Indeed, any national machine tool industry, it may be argued, best acquits its support function for the machine-using economy when its skills can be effectively transferred by intense and close interaction between its skilled personnel and the skilled personnel in its supplier and user industries. It would appear that the Korean machine tool industry is characterised by this sort of interaction and is, accordingly, beginning to fulfil the support function intended for it.

Notes

1. A few more recent studies have also paid greater than usual attention to technology; see, for example, Enos and Park (1988).
2. Von Hippel (1988: 121) suggests that process equipment innovations made by semiconductor producers not only improved their own competitive position, but were easily transferred to local equipment builders which, because of their proximity, were usually the first in the field to introduce the new technique. Other equipment users in the same area, which had not been involved in the original innovation, but which were supplied by the same equipment manufacturer, were usually among the first to implement the new development. In addition, the purchasers of the semiconductors gained access to the improved (or cheaper) product before their more distant competitors. If such a system is not operating, producers relying on imported equipment will be late users of new innovations developed in other countries, and will consequently remain several steps behind leading producers in those countries. Local equipment manufacturers no longer have access to developments made to equipment at the leading edge. And semiconductor producers requiring the newest and fastest chips will also have to rely on foreign supplies.
3. As already noted, the precise role of government in Japan's industrial development has been greatly debated. However, the Japanese government did implement many measures to encourage and support the expansion and technical development of the machine tool industry.
4. The Korean government's high levels of subsidy to the vehicle and shipbuilding industries, and the length of time over which these were available, demonstrate the government's commitment to industrialisation and its preparedness to support infant industries over an extended period. The Korean government's continuing long-term perspective on economic development is illustrated in a recent collection of papers considering the country's "transition to maturity" into the 21st century (Leipziger, 1988).

APPENDICES

APPENDIX I

Case Study Methodology and Questionnaire

The case study was undertaken by the author, who visited Korea from March to July 1985. During this time the author received considerable assistance from many Korean academics and researchers, who introduced her to industrialists and other researchers in the CNC machine tool and related industries. In particular, Mr. Kim Hwan Suk aided by interpreting in some interviews and undertaking translation work. Data were obtained from the sample firms by interview and by questionnaire. (The selection of the sample firms is described in Chapter 6.) The author also conducted extensive supplementary interviews in Korea with academics and staff at research institutes, industry associations, machine tool users, and non-CNC machine tool producers.

Each sample firm was visited at least once; in some cases several visits were made either to the same plant or to different plants or offices of the same firm. On each visit personnel in the firm were interviewed and, where possible, manufacturing facilities were directly observed. Brochures on the firms' products and, in some cases, annual reports on the firms' organisation and development were collected during these visits. A questionnaire, in Korean, was left with the interviewee at each of the firms (a copy, in English, is included at the end of this appendix). Responses to this questionnaire were highly satisfactory. All were returned; most supplied information in reasonable detail. In some cases, after the questionnaire had been returned, it was possible to revisit the firm to discuss information given in the questionnaire. All the firms were willing to help and there was little secrecy about their history, products or strategy. Secrecy was only encountered in respect of defence work undertaken by many of the firms. In some firms, defence production meant that it was not possible to visit the entire production plant.

All the interviews were undertaken at the plant or office of the interviewee and usually lasted between one and two hours. Interviews were conducted in both English and Korean; in the latter case, Mr. Kim

Hwan Suk interpreted for the author. Comprehensive notes were taken during the interview and were transcribed shortly thereafter. The jobs of the interviewees and their positions in the management structure of the firms varied. In the majority of cases interviewees were in product development or technical managerial positions. Typical interviewees included the development director, the general manager of the development or design office,^{and} the chief mechanical engineer or section manager of the production engineering department. Interviewees all had considerable knowledge of the technical features of the machines being produced and developed by the firms, the technological capabilities of personnel, and plans for future product developments. In some cases, the president of the firm, its managing director, and other directors were also interviewed. All interviewees had been with their respective firms for several years and, therefore, knew the histories of any foreign technology agreements entered into, collaborative projects with research institutes, and the development of various models of machine tool manufactured.

The interviews centred on the technical development of the firm, its entry into CNC production, and details of subsequent product and production developments. Securing data on the origins of the firm, its initial entry into the production of conventional machine tools, and its entry into CNC machine tools formed the initial part of the interview. Detailed case histories of the development of the firm's complete range of CNC machine tools were then built up. Critical information in these case histories included the type of design used, sources of technical help in the design and production of these machines, and modifications and improvements made to the design. Attention was also given to the acquisition of electrical/electronics and software skills in the design and manufacture of interfaces, and the operation of control units. The work of the design department was fully considered. This covered both the number and capabilities of the personnel within the department and the type of design work they were undertaking. Problems with access to component vendors and subcontractors, and any technical or production support from these suppliers, especially controls suppliers, were also investigated. Finally, interviews discussed entry into the production of

(i) critical CNC machine tool components, and (ii) FMS, FMC, and other automated systems.

In the case of the *chaebol* firms, additional information on the links between the machine tool producing division and other engineering divisions within the conglomerate was gathered during the interview. This included details of the internal market within the *chaebol* for machine tools, and technical links with other divisions and central research and development facilities. Where possible, any such central research and development facilities undertaking collaborative research on either CNC machine tools or automated systems were included in the investigative visits.

Direct observations of the firms' production facilities provided in-depth knowledge of the machinery and production methods being utilised. For example, the number of CNC machines being used in production and the origins of production machinery were easily visible. Moreover, from this visit a general assessment of the vertical integration of the plant could be made. Problems in production and assembly of machine tools, quality control, and stock control were also frequently discussed while surveying production facilities.

The questionnaire left with the firms was designed to elicit supplementary information about the company, its development and products; it also covered many details of the firm's production and development which could not be discussed in detail during the interview. Statistical data dealing with the firm's turnover during the previous four years, its profitability during this period, size of machine tool production (by value and units), and the proportion of this production devoted to CNC machinery were all gathered in this way. Most of the production and export data used in the study come from questionnaire responses, but some additional figures have been taken from Machine Tool, a Korean journal published by KOMMA, which lists production and trade data by product and by firm. Other sections of the questionnaire covered employment and training in the firm, technology agreements, the firm's major markets (both domestic and export), and the sourcing of key

components. The brochures collected on the firm's products provided the technical specifications of its products, and the details of the range of machine tools produced, both conventional and CNC.

In order to obtain more information on the Korean machine tool industry as part of an entire industrial system, two other types of firm were included. Firstly, several large machine tool users were visited and interviewed, in order to find out how close the technological inter-firm linkages between users and producers were and to make some assessment of the current market for CNC machine tools. In some cases, these machine tool users were part of the same *chaebol* which had divisions manufacturing machine tools. A main aim of these interviews was to map the transfer, if any, of skills and capabilities from machine tool producers to users, and to establish the internal market provided by the *chaebol* for its own machine tools. Secondly, the main supplier of control units and servo-motors to the Korean producers was visited. This firm was a Japanese-Korean joint venture. Again, the interview focussed on the transfer of skills and capabilities between users and this supplier.

To complete the case study, further interviews and visits were conducted at research institutes and industry associations which have close links with the machine tool industry: these included KAIST, KIMM, KOMMA, KOSAMI, and SMIPC. In the case of KAIST and KIMM, details of collaborative development projects with machine tool producers and training programmes for CNC machine tool producers and users were discussed. Interviews at the industry associations, KOMMA, KOSAMI and SMIPC, considered the promotion of the industry in the domestic and export markets, governmental policy and measures specific to the machine tool industry, and international trade relations. The interview with SMIPC also covered the training schemes and design consultancy service it runs for its members.

QUESTIONNAIRE

(This questionnaire was translated into Korean for distribution to the sample firms.)

I. General Background Information

1. Name of firm:
2. When was the firm established?
3. What was the firm's original product area?
4. When did the firm start to produce machine tools?
When did the firm start to produce CNC machine tools?
5. Is the firm part of a larger group?
What are the group's other major products?
6. What is the size of the firm in terms of:
 - (a) Capital: Is any of this foreign equity?
 - (b) Annual turnover, over the last four years
 - (c) Number of employees, over the last four years
 - (d) Approximate pre-tax profits as a percentage of gross value of sales
 - (e) Sales of machine tools, by value, over the last four years
7. Of the machine tools sold in the last four years, how many were conventional and how many were CNC?
8. What are the firm's two most important products, in terms of sales value?
9. What are the firm's two most important CNC machines, in terms of sales value?
Note: These two machines are later referred to as CNC 1 and CNC 2.

II. Product Design and Improvement

1. Where did the design for your first conventional machine tool originate? And for your first CNC machine tool?

2. In terms of the design of the machine body, how do your CNC lathes and milling machines differ from your conventional lathes and milling machines?
3. What are your two newest models of machine tool?
4. When did you start to produce these?
5. Are these totally new products or just improvements on existing models?
6. Which of the following have been important in the development of CNC 1 and CNC 2?

	<u>CNC 1</u>	<u>CNC 2</u>
(a) Licensing agreements	1 2 3 4	1 2 3 4
(b) Joint ventures/ foreign investment	1 2 3 4	1 2 3 4
(c) Parent company	1 2 3 4	1 2 3 4
(d) Foreign consultants	1 2 3 4	1 2 3 4
(e) Domestic consultants/ research institutes	1 2 3 4	1 2 3 4
(f) Other (please specify)	1 2 3 4	1 2 3 4

1 = Very important

2 = Important

3 = Some importance

4 = Unimportant

N.B. These numbers are used throughout the questionnaire.

7. For CNC 1 and CNC 2, have you made any alterations to these since their original launch? Were these improvements in quality or cost?

8. Which of the following in your machine tools are you anxious to improve?
- | | |
|----------------------------|---------|
| (a) Drives and motors | 1 2 3 4 |
| (b) Sensors | 1 2 3 4 |
| (c) Control | 1 2 3 4 |
| (d) Rigidity | 1 2 3 4 |
| (e) Other (please specify) | 1 2 3 4 |
9. For CNC 1 and CNC 2, how standardised are these products?
 -What sort of optional extras can you supply?
 -How much custom design will you undertake to meet the requirements of a particular customer?
10. How important are the following as sources for product improvements?
- | | |
|---|---------|
| (a) Purchase of turnkey plant/equipment | 1 2 3 4 |
| (b) Licensing agreements/joint ventures | 1 2 3 4 |
| (c) Foreign consultants | 1 2 3 4 |
| (d) Domestic consultants or research institutes | 1 2 3 4 |
| (e) Parent company or other part of group | 1 2 3 4 |
| (f) Technical staff within the firm | 1 2 3 4 |
| (g) Worker suggestions | 1 2 3 4 |
| (h) Customer suggestions - Domestic | 1 2 3 4 |
| - Foreign | 1 2 3 4 |
| (i) Competitors' products | 1 2 3 4 |
| (j) Professional or trade publications | 1 2 3 4 |
| (k) Other (please specify) | 1 2 3 4 |
11. Do you have any formal or informal methods for identifying changes in user needs in:
- | |
|-------------------------|
| (a) the domestic market |
| (b) the export market |
12. Among the components you buy in to fit to your machine tools, do you have any plans to produce any?
13. Could you list any licensing agreements/joint ventures your firm has entered into.

14. What do you consider to be the most important benefits you gained from these agreements?
15. Does your firm have, or plan to acquire, a CAD system?
16. In the next five years, what do you think will be the major changes made to your products?

III. Controls

1. Whose control units do you fit to your CNC machine tools?
2. Have you ever considered, or are you considering, in-house production of the control unit?
3. Do you do all the interfacing work for your machines tools?
- Have you ever had any help in this area from anyone?
4. Do you adapt in any way the control units you buy in?
5. For the solution of problems in control, how important are the following?

(a) Controls producers	1 2 3 4
(b) Foreign consultants	1 2 3 4
(c) Domestic consultants/ research institutes	1 2 3 4
6. What is your relationship with the controls supplier?
7. With the increasing trend towards further automation, how do you think this will affect your firm and your range of products?

IV. Market Structure and Competition

1. What proportion of your machine tool production is exported?
2. What proportion of your CNC machine tool production is exported?
3. Of your machine tool exports, what proportion of this goes to:
 - (a) Industrialised countries
 - (b) Less developed countries
 - (c) Newly industrialising countries
(e.g., Taiwan, Singapore, Hong Kong)

4. Where are your major export markets?
5. On the domestic market, how important are sales to the following?

(a) Large companies	Please, list in order
(b) Medium sized firms	of importance in terms of
(c) Small firms	sales value.
(d) Other parts of your group	
6. What are your customers' major products?
7. If you stopped producing CNC 1 or CNC 2, how much difficulty would your customers have in finding an alternative supplier?
 - (a) On the domestic market
 - (b) On the export market
8. Which of the following areas are you most concerned about improving to make your CNC machine more competitive?

(a) Price	Please, list in order
(b) Quality/performance	of importance.
(c) Delivery	
(d) Repairs and other customer services	
(e) Other (please specify)	
9. In the next five years who do you think will be your main competitors (by nationality) in foreign markets?

V. Costs

1. What are the prices of CNC 1 and CNC 2?
 - (a) On the domestic market
 - (b) On the foreign market
2. For these prices approximately what percentage is made up of:-
 - (a) Cost of the control unit
 - (b) Cost of other components
 - (c) Cost of materials
 - (d) Cost of sub-contracted work
 - (e) Factory overheads and labour costs
 - (f) R and D
 - (g) Payment of royalties

3. Of the bought-in components, which of these have to be imported into Korea and which are produced by other Korean firms?

VI. Manpower and Skills

1. What number of your employees are in the following areas?
 - (a) Research and development
 - (b) Core design
 - (c) Detailed design
 - (d) Management
 - (e) Repairs and maintenance
 - (f) Skilled work in production
 - (g) Manual work in production

For employees in sections a, b, and c only

2. How many of these employees are involved in mechanical engineering activities, and in electrical/electronics activities?
3. How many of these employees have the following degrees or formal technical training?
 - (a) Post-graduate degrees in science or engineering (Ph.D. or M.Sc.)
 - (b) Bachelor's degree in science or engineering (B.Sc.)
 - (c) Some form of other technical training after leaving high school
4. Did any of these people obtain their technical training abroad?
- If yes, how many and in which countries?

5. How many people work in the following activities and for approximately what percentage of their time?

	<u>Number</u>	<u>% of time</u>
(a) Quality control		
(b) Product improvements		
(c) Developing new products		
(d) Production improvements		
(e) Custom design		

For all employees

6. Does the company have any formal or informal policy for furthering the technical education of its employees?
7. If a key person in areas a-f left, in which areas would you have difficulty in finding a replacement?
8. If the firm decides to develop a new area of skills, are you most likely to recruit from within and train or recruit from outside?
9. Do you have a formal R&D department?
- What was its annual budget for the last four years?
- Is this department just for machine tool development or for all your company's products?

VII. Production

1. Of your production machines, how many are CNC?
- How many are machines you have produced in-house?
- How many are Korean made?
- (Please give approximate percentages)
2. Have you automated any of your production processes?
- Are you planning to?
3. How is your production planned and controlled?

4. What significant changes have you seen in your production methods in the last five years?

How important have the following been in motivating these improvements?

- | | |
|---|---------|
| (a) Reduction in product price | 1 2 3 4 |
| (b) Improvements in product quality | 1 2 3 4 |
| (c) Reduction in labour costs | 1 2 3 4 |
| (d) Reduction in energy costs | 1 2 3 4 |
| (e) Reduction in material costs | 1 2 3 4 |
| (f) Government grants or
incentives (Please specify) | 1 2 3 4 |
| (g) Other (Please specify) | 1 2 3 4 |

5. Which of the following have been important sources of technology for improving your production methods?

- | | |
|---|---------|
| (a) Purchase of turnkey plant/equipment | 1 2 3 4 |
| (b) Licensing agreements | 1 2 3 4 |
| (c) Joint ventures | 1 2 3 4 |
| (d) Foreign consultants | 1 2 3 4 |
| (e) Domestic consultants or research institutes | 1 2 3 4 |
| (f) Parent company or other part of group | 1 2 3 4 |
| (g) Technical staff within the firm | 1 2 3 4 |
| (h) Worker suggestions | 1 2 3 4 |
| (i) Customer suggestions | 1 2 3 4 |

6. In the next five years in what ways do you think your production facilities will change?

APPENDIX II

The Korean Machine Tool Industry after 1985

This appendix briefly summarises some developments in the Korean machine tool industry subsequent to the time of the case study research in 1985. Korea's demand for machine tools has continued to grow rapidly and, in the main, this growth has been the result of continuing investment and automation in the domestic vehicle industry. The Korean machine tool industry has expanded at a rate equivalent to that of its consumers maintaining its share of the domestic market. The orientation of the industry towards this domestic market has been continued, and exports have increased only slowly. (As a proportion of total output, exports have actually decreased significantly.)

Table A1 Korean Machine Tool Statistics 1985-87
(in million US\$)

	1985	1986	1987
Production	184,0	333,5	505,5
Export	25,0	27,0	40,0
Import	150,0	358,0	400,0
Consumption	309,0	664,5	865,5

Source: American Machinist, various issues.

There are also indications of continuing technical development. A further six machine tool firms have commenced CNC production, and the overall share of CNC output in total production had reached 32% by 1986 (Lee Hae, 1987: 4). The leading machine tool firms have continued to develop and install more automated equipment in collaboration with users, thus fulfilling their support role. For example, Firm B has developed two FMSs, which are used to manufacture cylinder blocks and crankshafts in the group's diesel engine plant. While a few Korean firms have acquired or enhanced their capabilities in the design and assembly of FMSs, there

are still many gaps in their electronics and software capabilities. Korean CNC producers remain as dependent as they were in 1985 on imported electrical and electronic components. Although the domestic manufacture of servo-motors has been promoted, only prototypes have so far been made and there have been no advances in control unit production.

The manufacture of automation equipment in Korea includes robotics, and developments in this field have been confined to the *chaebol* firms. In general, their robot developments have been closely aligned to each *chaebol's* internal demands, i.e., those *chaebol* which concentrate on vehicle manufacture and large-scale engineering production have developed robots to undertake such tasks as welding, while those in the electronics sector have concentrated on assembly applications (Lee Chong Won, 1987: 12-17; Kim Linsu, 1987: 15). Requirements of large divisions of the group have dictated the direction of technical developments, and the extremely close collaboration of producer and user has aided the learning process. Thus, patterns of interaction and innovation in the production of automation equipment appear to be proceeding along lines familiar from the machine tool industry itself.

Although the Korean government has been less directive in industrial development since 1984-85, it has continued to watch over industry and, where it considered it necessary, to reorganise sectors by merging failing firms. Included in such government actions was the takeover of *Chaebol E* by *Chaebol D* in early 1986. The transfer of ownership was accompanied by many incentives, including tax exemptions and reductions, and some of *Chaebol E's* debts to the government were written off. As well as the financial incentives, a major benefit for *Chaebol D* from taking over this firm is the acquisition of extensive property holdings of the company throughout Korea. (Normally the process by which groups acquire large landholdings is made difficult for the *chaebol* by various government regulations.) Of these properties, it is widely anticipated that the very large area of land on the Changwon Industrial Complex, where Firm E was located, will be used for a new vehicle assembly plant that *Chaebol D* plans to build as a joint venture with Ford (Butler, 1986).

The Korean government's strategy of avoiding retaliatory trade restrictions by negotiating with the US authorities at an early stage appears to have been successful. As noted earlier, in late 1986 Japan, Taiwan, West Germany, and Switzerland were forced to enter "voluntary" restraint agreements limiting their machine tool exports to the US, and Korea, along with several other countries, was warned not to rapidly increase its exports to the US. In mid-1987, following trade talks, the US Secretary of Commerce pledged that Korean exports of cars, semiconductors, and machine tools to the US would not be restricted (EIU, 1987b: 11).

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Details of unsigned newspaper and periodical items are fully cited in text references and are not repeated here. Abbreviations used here and not detailed in front matter include: ECLA = Economic Commission for Latin America; EIU = Economist Intelligence Unit; IDB = Inter-American Development Bank; ILO = International Labor Organization; KDI = Korean Development Institute; KIRI = Korea Industrial Research Institutes; NMTBA = National Machine Tool Builders Association (US); OECD = Organization for Economic Cooperation and Development; UNCTAD = United Nations Commission for Trade and Development; UNIDO = United Nations Industrial Development Organization. All Korean, and most Chinese and Japanese, names are given in full form here and in the text.

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